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ENVIRONMENTAL ECONOMIC ISSUES IN THE SOUR GAS PROCESSING INDUSTRY IN ALBERTA

by

© JOHN WILLIAM JANKE

A THESIS

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ENVIRONMENTAL ECONOMIC ISSUES IN THE SOUR GAS PROCESSING INDUSTRY IN ALBERTA. submitted by JOHN WILLIAM JANKE in partial fulfilment of the requirements for the degree of Master of ARTS.

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ABSTRACT

This thesis discusses the theoretical concepts of environmental economic analysis in the context of the sour gas processing industry in Alberta. The general desirability of superimposing some form of corrective paternalistic intervention onto the individualistic decision-making process was established by summarizing the literature on externalities and public goods, and by discussing the pragmatic difficulties associated with private bargaining. Following a summary of certain technical and regulatory aspects of the industry, a simplified benefit-cost model was presented, and the nature, and--to a very limited degree--the extent, of external costs arising out of sour gas production and processing operations were discussed through reference to actual litigation.

It was then argued that the regulatory bodies' issuance of guidelines requiring enhanced sulphur recovery at certain gas plants could probably not be justified on the basis of documented damage claims, but that legally-acknowledged damages were likely to constitute only a small proportion of the true total damages. Finally, it was concluded that the government's goal of reducing total sulphur emissions to the atmosphere was being constrained by it desire to permit certain operators to earn from seven to ten per cent on their total undepreciated investment in

sulphur recovery facilities, and that compromises of this nature would likely prevail until social scientists were able to provide a more exact quantification of external costs.

ACKNOWLEDGEMENT

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CHAPTER I

INTRODUCTION

This study attempts to relate the concepts of contemporary environmental economic analysis to the air pollution problem which arises from sour gas processing in Alberta. Due to its great potential for environmental disruption, the natural gas industry has been a somewhat-mixed blessing to citizens in the vicinity of certain production and processing facilities. This problem is of special interest to economists because--as in all pollution situations--the presence of externalities and public goods results in market failure, and, therefore, the need for government intervention.

Hydrogen sulphide, a gas which is highly toxic and corrosive even in minute quantities, is associated--in concentrations as high as 53 per cent of the plant inlet stream--with the normal constituents of sales gas (principally methane and ethane) in 64 of the 152 conventional gas processing plants in the province. This gas, and trace quantities of other sulphur compounds, must either be largely converted to elemental sulphur by means of complex, expensive equipment, or completely burned and released to the atmosphere as sulphur dioxide, which is somewhat less toxic.[1]

---

[1] Only plants with very low sulphur inlet capacities are allowed to flare all of their H_2S to SO_2: most facilities are now required to convert at least 90 per cent to the elemental form.

The emission of considerable quantities of SO_2,[1] and the emanation of sulphurous odors from condensate storage tanks, flare stacks, burn pits, and other plant-site facilities, has invoked many complaints from persons residing near gas plants. Past operations are alleged to have caused or contributed to, inter alia: human afflictions such as eye irritations, respiratory ailments, nauseau, skin eruptions, and headaches; damage to vegetation; illness and reduced litters in farm animals; accelerated corrosion of farm equipment; blackening of paint; and declines in property values.[2]

These, and other, externalities have lead to political agitation, prolonged litigation, and increasingly stringent controls on the nature and extent of field flaring, as well as the amount and concentration of SO_2 discharged to the atmosphere. The regulations pertaining to sulphur dioxide are of particular relevance to the present study, and are of three basic types: specifications of maximum permissible ambient concentrations over various periods of time; SO_2 discharge permits; and sulphur efficiency recovery "guidelines" which specify the percentage of total inlet sulphur that must be recovered in elemental form. The guidelines--issued in November, 1971[1]--are more stringent than previous recovery efficiency controls, and are intended to be only slightly more flexible than "regulations." They will be enforced by January 1, 1975;[2] reflect growing concern about the total amount of SO_2 emissions; and state that all existing and future plants in Alberta recover--depending upon total sulphur inlet capacity and CO_2 content of the acid gas-- from 90 per cent to 99 per cent of all inlet sulphur. Additional capital expenditures attributable to the guidelines were estimated--at the time of their issuance--to be at least thirty million dollars.[3]

---

[1] Sulphur dioxide emissions averaged approximately 1300 LT/D (long tons per day) during the year ended June 30, 1972. Alberta, Energy Resources Conservation Board (ERCB), Status of Environment Protection in Alberta Energy Resource Industries, Report 72-F, (Calgary: 1972), p. 6-3. A long ton is equal to 2240 pounds.

[2] In addition, the difficulty of containing sulphur dust which originates from the storage and loading of the solid element has caused soil acidification and water pollution.

As a result of the revised standards, about fifteen operators who had designed their gas plants on the basis of earlier--and lower--standards, suddenly found themselves several percentage points deficient, and faced the rather grim prospect of having to expend considerable sums of money to remedy the situation. These incremental expenditures on sulphur recovery were usually ascertained to be "uneconomic"--

---

[1] ERCB, Sulphur Recovery Requirements: Gas Processing Operations, Informational Letter No. IL-29, (Calgary: 1971).

[2] Material shortages, coupled with delays in the processing of applications for approval of the proposed remedial work or exemption from the guidelines, have made it impossible for all plants to meet the deadline.

[3] ERCB, Status of Environmental Protection, p. 6-17.

within the partial equilibrium framework of the individual operator--due to the very small additional amounts of sulphur to be recovered and the extremely low price of sulphur which prevailed in 1972 and early 1973. Many operators therefore applied for full or partial exemption from the guidelines on the basis of plant economics. They stated that their current levels of emission were not causing environmental damage, and, to further justify their applications, occasionally cited special engineering considerations, such as: expected declines in plant throughput, anticipated sweet gas breakthrough, or a high proportion of carbon dioxide in the acid gas.

The firms' applications were, therefore, based solely on considerations of profit maximization.[1] However, this objective is inconsistent with welfare maximization if externalities are, in fact, present: therefore, a much broader, "social" benefit-cost framework must be utilized in the determination of the optimal level of pollution abatement.

Purpose:

The purpose of this thesis is therefore three-fold: first, to establish a sound theoretical framework by surveying and summarizing the relevant analytical literature on externalities and public goods; second, to discuss pollution abatement in the sour gas processing industry in a social benefit--social cost framework; and, finally, to discuss the enhanced sulphur recovery guidelines from the standpoint of welfare economics. Inasmuch as the study is primarily devoted to a discussion of analytic concepts, it is basically of a qualitative, rather than quantitative, orientation. It is hoped that the report will therefore be of some utility when more detailed socio-economic research is designed.

---

[1] The ERCB eventually established a compromise policy based not on an incremental rate of return--which would have invariably been negative--but on a "total" rate of return. Infra, p. 100.

Data Sources:

Institutional information was obtained primarily from Energy Resources Conservation Board (ERCB) documents and several well-respected industry periodicals. Information concerning costs of pollution was obtained from transcripts of Public Hearings held throughout Alberta in October, 1972, and from Southern Alberta Supreme Court Files. Abatement cost data was obtained from ERCB decisions pertaining to requests for exemption from the enhanced sulphur recovery efficiency guidelines.

Format:

Chapter II summarizes the conclusions of modern welfare economics and demonstrates that, due to the presence of external effects and public good phenomena, unfettered free market activity is likely to result in "too much" pollution. Chapter III expands upon the institutional and regulatory framework alluded to in the opening section of this introduction, so as to expedite an understanding of the complexity of the problem and the reasoning behind the regulations that have evolved. Chapter IV develops a simplified benefit cost model and discusses the nature of the externalities which precipitated litigation at Pincher Creek. It then applies the welfare-maximizing criterion to the incremental abatement expenditures which the ERCB has imposed on many operators, attempts to explain the apparent divergence therefrom in terms of "hidden pollution costs," and assesses the extent to which the enhanced sulphur recovery guidelines display cognizance of these extra costs. Finally, Chapter V is comprised of a unifying summary of the concepts and findings, a description of the limitations of this report, and a discussion of the direction that further, more detailed, research should take.

CHAPTER II

THE ECONOMIC THEORY OF POLLUTION AND POLLUTION ABATEMENT

What is Pollution?

The layman's conception of pollution as the disposal of residual products of consumption and production activities is not entirely correct. Pollution does not, in fact, occur unless the residuals adversely affect the production and/or consumption activities of other individuals. In the somewhat cryptic language of the economist, pollution is a "negative technological externality," and results from the lack of clearly defined property rights.

The purpose of this chapter is to show that the presence of these "externalities," and the closely-related phenomenon of "public goods," can lead to a situation wherein the free market mechanism fails to allocate resources efficiently and/or alters the distribution of income. Therefore, if information and enforcement costs are sufficiently small, government intervention may improve upon the market-generated solution, and the demonstration of this fact may be facilitated by a restatement of the assumptions and conclusions of modern welfare economics.

The Invisible Hand and Pareto Optimality

The notion that the price system, unburdened by government encumberances, would automatically attain the highest attainable level of social welfare was first advanced by Adam Smith almost two centuries ago:

> Every individual endeavours to employ his capital so that its produce may be of greatest value. He generally neither intends to promote the public interest, nor knows how much he is promoting it. He intends only his own security, only his own gain. And he is in this led by an Invisible Hand to promote an end which was no part of his intention. By pursuing his own interest he frequently promotes that of society more effectually than when he really intends to promote it.[1]

Modern welfare economics provides the contemporary analogue: under the stringent conditions of the model of perfect competition, there exists a unique, positive, price vector that is simultaneously compatible with both profit maximization by all firms and utility maximization by all consumers. Furthermore, it may be demonstrated that the resultant competitive equilibrium implies a state of Pareto optimality, i.e., a situation from which it is impossible to make anyone better off without making at least one person worse off. The model of perfect competition that leads to this result usually makes the following sorts of assumptions: enough buyers and sellers to ensure that none can affect the price; strict convexity of production functions and indifference curves; constant returns to scale; irreversibility of the production process; perfect knowledge of both the present and future; perfect factor mobility (a spaceless economy is usually assumed); free entry and exit of firms;

---

[1] Adam Smith, An Inquiry into the Nature and Causes of The Wealth of Nations, 1776, cited by Paul A. Samuelson, and A. Scott, Economics: An Introductory Analysis, Second Canadian Edition, (Tornonto: McGraw-Hill, 1968), p. 44.

profit and utility maximization by firms and consumers respectively; perfect divisibility of all inputs and outputs; and, the absence of production and consumption externalities.[1]

Obviously, the required conditions seldom, if ever, occur in any sector of the real world, and, in our present context, an assessment of the allocative and distributive effects (if any) of technical externalities is therefore in order.

Externalities

Externalities occur whenever the activities of one person affect the well-being or production functions of people who have no direct (*i.e.*, market) control over those activities. In mathematical terms, an externality is present when:

$$u^A = u^A\ (X_1, X_2, \ldots, X_M, Y_1)$$

i.e., the utility of person A depends upon those consumption activities ($X_1, X_2, \ldots, X_M$) which are under his exclusive control, as well as upon the production or consumption activity Y_1, which is under someone else's control.[2]

---

[1] This model admittedly constitutes a polar case: however, it aptly demonstrates the type of situation that must prevail *if* social welfare is to be maximized.

The same conclusion regarding Pareto optimality can also be reached under slightly different axiom systems. For a good summary of six such systems, see James Quirk and Reuben Saposnik, *Introduction to General Equilibrium Theory and Welfare Economics*, (New York: McGraw-Hill, 1968) pp. 100-102.

[2] James M. Buchanan and William C. Stubblebine, "Externality" *Economica*, XXIX, No. 116 (1962), pp. 371-384.

The early literature tended to treat externalities as minor, infrequent, anomalies which did not seriously invalidate the conclusions derived from models which assumed independent production and consumption functions.[1]

It was felt that the divergence between private and total[2] costs and benefits could be reconciled by fairly simplistic ad hoc measures, and the "Pigovian" solution was, therefore, to make the polluter responsible for damages, to levy an excise tax on output,[3] or to forbid certain industrial activities from residential areas.

Due to a curious admixture of ambiguity, conventional wisdom, and tradition, these views went almost unchallenged until 1960. Then Professor Coase, in a path-finding article, demonstrated (under rather restrictive conditions) that the allocation of resources does not depend upon how the costs of pollution are borne.[1] Coase began by stressing the reciprocal nature of the problem: if A harms B, and B subsequently obtains injunctive (or other) relief, is not A hurt instead? Water pollution from a refinery may well impose costs on downstream users: however, corrective action imposes costs on the refinery. The challenge, therefore, is to avoid the more serious harm.

---

[1] Recent research has conclusively demonstrated that externalities are an inevitable consequence of economic activity. Ayres and Kneese, utilizing the Law of Conservation of Matter, have shown that in a closed economy with no net accumulation of stocks the weight of residual products is at least as great as that of the basic fuels, food, and raw materials entering the production system. For a detailed desription of the "Materials Balance" approach, see Robert U. Ayres and Allen V. Kneese, "Production, Consumption and Externalities," American Economic Review, LIX, June 1969, pp. 282-297.

[2] In the current context, the term "total" refers to the sum of private and external costs or benefits.

[3] The "corrected" allocation of resources and level of output will depend upon whether the emission, the saleable product, or the offending input is taxed. The literature is often very vague as to what, in fact, is being penalized. Except under very special conditions, however, it would appear that the emission should be taxed. For an elaboration, see Charles R. Plott, "Externalities and Corrective Taxes," Economica, XXXIII, No. 129 (1966), pp. 84-87.

Coase cited many precedents from various jurisdictions wherein the courts and legislators have been cognizant of the desirability of comparing the benefits of industrial and commercial activities with the external costs imposed on others. If, for example, a railway franchise is granted under statutory authority, persons residing in the immediate vicinity would have to tolerate the noise and smoke resulting from "normal" operations. In order to accomodate the "greater good", injunctive relief or damages would be awarded only under very unusual circumstances.

The central implication of Coase's research was that--given costless bargaining and perfectly competitive markets--the allocation of resources is the same regardless of which party bears the damages: therefore, only a redistribution of income is involved. If the affected party (B) does not have any legal rights and stands to lose more at the margin than the polluter (A) stands to gain (again, at the margin) through the deleterious activity, both parties can be made better off by the simple expedient of B bribing A to reduce his effluent. The potential bribe thus becomes an opportunity cost to A of continuing to pollute, and incentive therefore exists to reduce pollution to the same level as would prevail if A were liable for damages.

---

[1] Ronald Coase, "The Problem of Social Cost," Journal of Law and Economics, III, No. 1 (1960), pp. 1-44.

The same argument is aptly presented by Crocker and Rogers:

> . . . a free market allows sufferers to pay perpetrators to cut down the pollution they are creating. This opportunity for the perpetrators to earn revenue in return for pollution reduction means that they must consider the costs their pollution is imposing on the sufferers. This opportunity cost forces them to consider as their own internal costs, effects that would otherwise be external to their opperations. If property rights are held by the sufferers, the perpetrator is forced to pay an explicit cost if he is to buy the right to use the resource in question for waste disposal. In either case, transactions will take place until the sum of the perpetrator's control costs plus the sum of the sufferers' damage costs are minimized.[1]

Turvey utilized an agricultural example to obtain the same conclusion:

---

[1] Thomas D. Crocker and A. J. Rogers III, Environmental Economics, (Hinsdale, Illinois: The Dryden Press, Inc., 1971), p. 68.

> Thus the absence or existence of the right on the part of the farmers *does not affect the allocation of resources between activities but only the distrubution of the gains and losses between the parties*. The law of nuisance is thus only relevant to the *fairness* of what happens.[1] (Italics mine).

Coase then applied his concept of reciprocal externalities to effluent taxes, which he also felt were a two-way street.[2] If a factory owner is required to pay a tax equal to damages inflicted upon residents, should not the residents be similarly required to pay a tax equal to the extra cost incurred by the factory owner to avoid the damage? For example, assume that a factory causing smoke damage of $100 per annum can avoid these damages by expending $90 per annum on abatement. Although the factory owner would be $10 better off (assuming that he would be taxed for the damages) by installing the control equipment, the situation will nevertheless not be optimal if the affected persons could take measures of their own (including moving away) to avoid pollution at a loss of income of only, say, $40 per annum. Under these circumstances, there would be a gain of $50 in the total value of production if the factory continued to emit its smoke.

---

[1] Ralph Turvey, "Side Effects of Resource Use", in Henry Jarrett, ed., *Environmental Quality in a Growing Economy*, (Baltimore: The Johns Hopkins Press for Resources for the Future, Inc., 1967), p. 55.

[2] Coase, "Social Costs," p. 41.

Dorfman, in concurring, pointed out the policy implications:

> Coase's major contribution here is to recognize that responsibility for damages is a reciprocal one, falling no less on the afflicted party to take steps to avoid them, than on the perpetrator. This insight has some profound implications for environmental policy. It suggests that, if optimal use of environmental resources is the sole object of policy, the responsibility for limiting the cost of environmental damage should be made to fall wherever it can be shouldered most cheaply rather than entirely on the initiator of the damages. In no event, for example, should a polluter be charged more than what it would cost the sufferers to take steps to avoid injury.[1]

Buchanan and Stubblebine also stressed the reciprocal nature of externalities in their rigorous mathematical article, which was published two years after the original Coase formulation.[2] To re-iterate, A's utility depends, in part, upon an activity Y_1 which is under the control of some other individual, B.[3] Let

$$u^A = u^A (X_1, X_2, \ldots, X_M, Y_1),$$

and

$$u^A_{Y_1} = \frac{\partial u^A}{\partial Y_1} \quad ;$$

where the change in Y_1 is measured with respect to those values of the X_i which combine with the given value of Y_1 to produce equilibrium.

---

[1] Robert S. Dorfman and Nancy S. Dorfman, editors, Economics of the Environment: Selected Readings, (New York: W. W. Norton and Co. Inc., 1972), pp. 66-67.

[2] Buchanan and Stubblebine, "Externality," pp. 372-373.

[3] Obviously, many other activities of B and other individuals may also affect A's utility. This possibility is, however, assumed away in order to isolate the effects of a single externality.

Then, marginal external economies occur when

$$u^A_{Y_1} > 0 ;$$

and marginal external diseconomies result if

$$u^A_{Y_1} < 0 .$$

An infra-marginal external economy exists when

$$u^A_{Y_1} = 0 \text{ but } \int_0^{Y_1} u^A_{Y_1} \, dy_1 > 0;$$

and an infra-marginal external diseconomy results if

$$u^A_{Y_1} = 0 \text{ but } \int_0^{Y_1} u^A_{Y_1} \, dy_1 < 0.$$

Hence, infra-marginal effects occur whenever small increments in the level of B's activity have no effect on A's utility, but the total effect of B's pursuing that particular activity has nevertheless been to increase (or decrease) A's satisfation.

Victor provides a good example of an infra-marginal externality:

> A lake can be made unsuitable for swimming if too much of certain types of effluent are discharged into it. However, after the lake becomes unsuitable for swimming, it may be able to accommodate a large inflow of additional effluent before it also becomes unsuitable for sailing. This additional effluent is an infra-marginal externality since, while the effluent in total damages the lake, marginal adjustments in the outflow over a certain range do not alter the extent of the damage.[1]

Buchanan and Stubblebine next define B's utility and production functions.

---

[1] Peter A. Victor, Economics of Pollution, (London, England: The MacMillan Press Ltd., 1972), pp. 19-20.

$$u^B = u^B\ (Y_1, Y_2, \ldots, Y_m)$$

$$f^B = f^B\ (Y_1, Y_2, \ldots, Y_m)$$

B maximizes utility when

$$\frac{u^B_{Y_1}}{u^B_{Y_j}} = \frac{f^B_{Y_1}}{f^B_{Y_j}}$$ [1]

i.e., the ratio of marginal utilities is equal to the marginal rate of transformation. Y_j (and later, X_j) refers to some activity involving a numeraire commodity or service which is available to A and B on equal terms. Designating the equilibrium values for the Y_i by $\overline{Y}_i$, potentially-relevant marginal external diseconomies are defined as:

$$u^A_{Y_1} \Big|_{Y_1 = \overline{Y}_1} < 0$$

A is clearly desirous of modifying B's behaviour. However, his actual *ability* to do so is contingent upon the marginal external diseconomy being "Pareto-relevant", *i.e.*, A's marginal rate of substitution must exceed B's "net" MRS:

$$(-)\ \frac{u^A_{Y_1}}{u^A_{X_j}} > \left[\frac{u^B_{Y_1}}{u^B_{Y_j}} - \frac{f^B_{Y_1}}{f^B_{Y_j}} \right] \Bigg|_{Y_1 = \overline{Y}_1};$$

and $$\frac{u^A_{Y_1}}{u^A_{X_j}} < 0.$$ [2]

---

[1] Buchanan and Stubblebine, "Externality," p. 373.

[2] *Ibid.*, pp. 374-375.

If the above conditions do not hold, A cannot be made better off without B being made worse off, i.e., no "gains from trade" (possibly through bribery) are possible.

The Pareto-optimal conditions are defined to be:

$$(-)\ \frac{u^A_{Y_1}}{u^A_{X_j}} = \left[\frac{u^B_{Y_1}}{u^B_{Y_j}} - \frac{f^B_{Y_1}}{f^B_{Y_j}}\right] ;$$

$$\frac{u^A_{Y_1}}{u^A_{X_j}} < 0.$$ [1]

Therefore, marginal externalities may exist in Pareto equilibrium, although Pareto-relevant externalities may not.

Referring again to infra-marginal externalities, we now wish to determine whether A can reach some mutually-acceptable arrangement with B to effect a discrete change in the level of activity Y_1. This will occur in the "diseconomy" case if

$$(-)\ \frac{\Delta u^A}{\Delta Y_1} \Big/ \frac{\Delta u^A}{\Delta X_j}$$ [2]

$$> \left[\frac{\Delta u^B}{\Delta Y_1} \Big/ \frac{\Delta u^B}{\Delta Y_j} - \frac{\Delta f^B}{\Delta Y_1} \Big/ \frac{\Delta f^B}{\Delta Y_j}\right]_{Y_1 = \bar{Y}_1}$$

---

[1] Although the authors develop analogous conditions for Pareto-relevant economies, only harmful side-effects shall hereinafter be considered.

[2] Ibid., p. 376.

In this case, potential relevance need not imply Pareto relevance since the right hand side need not equal zero when B is in utility-maximizing equilibrium.

Buchanan and Stubblebine then utilize their previously-developed definitions in a diagramatic solution of a practical problem. On the basis of this example and their mathematical derivations they conclude that:

> There is not a *prima facie* case for intervention in all cases where an externality is observed to exist. The internal benefits from carrying out the activity, net of costs, may be greater than the external damage that it imposed on the other parties.[1]

Again, the reciprocal nature of externalities--first expounded by Coase--is abundantly clear.

The methodical, painstaking simplicity of Coase's numerical and verbal analysis made it almost impossible for most economists not to seriously question the entire "traditional" method of dealing with externalities, and any disbelievers were probably soon converted by the more exotic mathematical articles which followed. Nevertheless, Coase-type solutions are not without their own serious shortcomings. Indeed, allocatively-inferior and politically-dangerous policy recommendations may be the end result of an unswerving faith in this method. Most of the difficulties stem from the stringent and somewhat unrealistic assumptions of the model--such as costless bargaining--and the blatant disregard of the arduousness of organizing for collective action. However, inasmuch as an analysis of collective behavior is at the interface of externalities and public goods, it was deemed advisable to defer criticism of the Coase approach until collective consumption goods have been discussed in some detail.

---

[1] *Ibid*., p. 381.

Public Goods

Public goods, or "collective consumption goods", are a closely-related cause of market failure. Although many theories had been advanced in Europe since 1850, very few were written in English, even during the first half of the Twentieth Century--Musgrave and Bowen being the notable exceptions.[1] Development of the topic was virtually dormant--especially when compared to advancements in the theories of imperfect competition, game theory, general equilibrium theory, and Keynesian macro-economics--until Samuelson published three articles in the mid-1950's.[2]

The first of Samuelson's articles provided precise mathematical definitions of two types of goods:

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[1] Richard A. Musgrave, "The Volutionary Exchange Theory of Public Economy," Quarterly Journal of Economics, LIII (February 1939), pp. 213-137; Howard R. Bowen, Toward Social Economy, (New York: Reinhart, 1948), especially Chapter 18.

[2] Paul A. Samuelson, "The Pure Theory of Public Expenditure," Review of Economics and Statistics, XXXVI, No. 4 (1954), pp. 387-389; "Diagrammatic Exposition of a Theory of Public Expenditure," RES, XXXVII No. 4 (1955), pp. 350-356; and "Aspects of Public Expenditure Theories," RES, XL No. 4 (1958), pp. 332-338.

1. Private Consumption Goods

These n goods, $(X_1, \ldots, X_n)$ can be divided among s different individuals according to the relation

$$X_j = \sum_{i=1}^{s} X_j^i, \quad \begin{matrix}(i = 1, \ldots, s);\\ (j = 1, \ldots, n).\end{matrix}$$

where X_j^i is the quantity of the j^{th} good consumed by the i^{th} individual.

Individual demand curves are added horizontally to obtain the market demand curve, and marginal rates of substitution are equated between individuals and to the marginal rate of transformation in production:

$$MRT = MRS_1 = MRS_2 = \ldots = MRS_s$$

2. Collective Consumption Goods

These m goods $(X_{n+1}, \ldots, X_{n+m})$ are enjoyed in common by all. Each individual's consumption of such a good leads to no subtraction from another individual's consumption of that good. Hence,

$$X_{n+j} = X_{n+j}^i \quad \begin{matrix}(i = 1, \ldots, s)\\ (j = 1, \ldots, m).\end{matrix}$$

Individual demand curves must now be added vertically, as must marginal rates of substitution. (A mathematical formulation is presented later in this chapter).

An example of a pure private good would be hamburger or any other foodstuff. National defence, lighthouses, and pollution abatement are frequently cited as the best examples of public goods.[1] In actual fact, of course, there are elements of both publicness and privateness in most goods. Enke and Margolis both cited many examples (such as police and fire protection, hospitals, highways, libraries) wherein the "consumption" of a good or service by one individual diminishes (however slightly) the quantity or the quality of that same good or service that another individual can enjoy.[2] Hence, pure public and pure private consumption goods are merely the polar extremes on a continuum of goods. Although there have been recent attempts to develop a theory which embraces the entire spectrum,[3] this section shall content itself with the pure situations inasmuch as they readily demonstrate the misallocation of resources that occurs when public good characteristics are present.

Samuelson lets

$$u_j^i = \frac{\partial u^i}{\partial x_j^i}$$

be the marginal utility of the j^{th} good to the i^{th} individual and then states the Pareto-optimal conditions for equating the ratio of marginal utilities to the ratio of marginal rates of transformation in production for all individuals and commodities:

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[1] It must be stressed that the distinction between private and public goods is based on the inherent technological characteristics of the goods and not political ideology. See Richard A. Musgrave, Fiscal Systems, (New Haven: Yale University Press, 1969) Chapter 1, for an elaboration of this point.

[2] Stephen Enke, "More on the Misuse of Mathematics in Economics: A Rejoinder," RES, XXXVII No. 4 (1955), pp. 131-133; Julius Margolis, "A Comment on the Pure Theory of Public Expenditure," RES, XXXVII No. 4 (1955), pp. 347-349.

[3] See, for example, David M. Winch, "The Pure Theory of Non-Pure Goods," Canadian Journal of Economics, VI, No. 2 (1973), pp. 149-163.

1. For Private Goods

$$\frac{u_j^i}{u_r^i} = \frac{F_j}{F_r} \qquad \begin{array}{l}(i = 1, \ldots, s;) \\ (r, j = 1, \ldots, n)\end{array}$$

2. For Public Goods

$$\sum_{i=1}^{s} \frac{u_{n+j}^i}{u_r^i} = \frac{F_{n+j}}{F_r}{}^{1} \qquad \begin{array}{l}(j = 1, \ldots, m); \\ (r = 1, \ldots, n).\end{array}$$

The above equations define the utility frontier, and, if the social welfare functions were given, we might be tempted to believe that we could still attain the "best state in the world" simply by utilizing costless lump-sum taxation and transfer payments. However, Samuelson noted that ". . . no decentralized pricing system can serve to determine optimally these levels of collective consumption."[2] Multiple pricing is now required, and it is "in the selfish interest of each person to give false signals, to pretend to have less interest in a given collective consumption activity than he really has . . . ."[3]

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[1] Samuelson "The Pure Theory," (1954), p. 387.

[2] Ibid., p. 388.

[3] Ibid., pp. 388-389.

Samuelson stated that the optimal solution does, in fact, exist--the problem is how to find it. Bator agreed:

> It is the central implication of the Samuelson model that where public good phenomena are present, there does not exist a set of prices associated with the (perfectly definable) bliss point, which would sustain the bliss configuration. The set of prices which would induce profit-seeking competitors to produce the optimal bill of goods, would be necessarily inefficient in allocating that bill of goods.[1]

A follow-up article by Samuelson one year later portrayed the results graphically for a two person, two commodity, (one private and one public), world.[2]

Indifference curves showing preferences for the public *vs*. the private good are constructed for each individual in Figures 1 and 2, and are combined with a regular production possibility curve AB in Figure 3.

Pareto-optimal points are determined in the following manner: Set Man 2 on a specified indifference curve--say, $U^{2''}$. Map this curve onto the production frontier diagram. Then the *vertical* distance between $U^{2''}$ and AB determines the amounts of the public and private goods available to

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[1] Francis M. Bator, "The Anatomy of Market Failure," *Quarterly Journal of Economics*, August 1958, LXXII, No. 3 (1958), p. 371.

[2] Samuelson, "Diagrammatic Exposition," (1955), pp. 350-356. A step-by-step method of extending the analysis to an n-person, n-commodity situation, can be found in James M. Buchanan, *The Demand and Supply of Public Goods*, (Chicago: Rand McNally and Company, 1968), pp. 77-85.

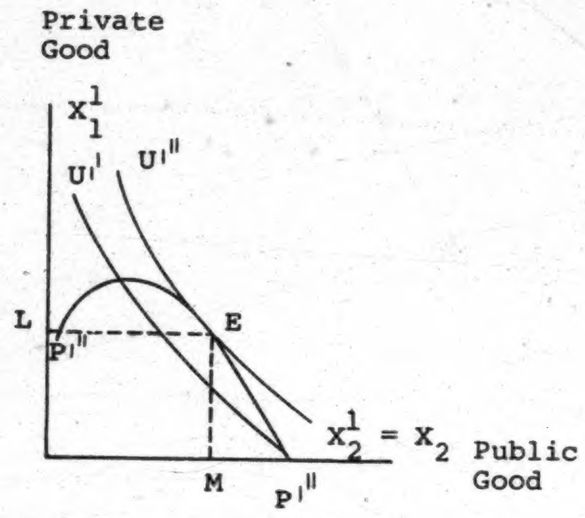

Figure 1 - Indifference Curves for Public vs. Private Goods for $\overline{\text{Man}}$ 1.

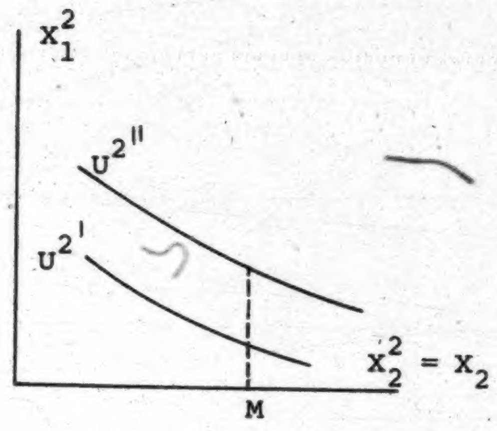

Figure 2 - Indifference Curves for Public vs. Private Goods for $\overline{\text{Man}}$ 2.

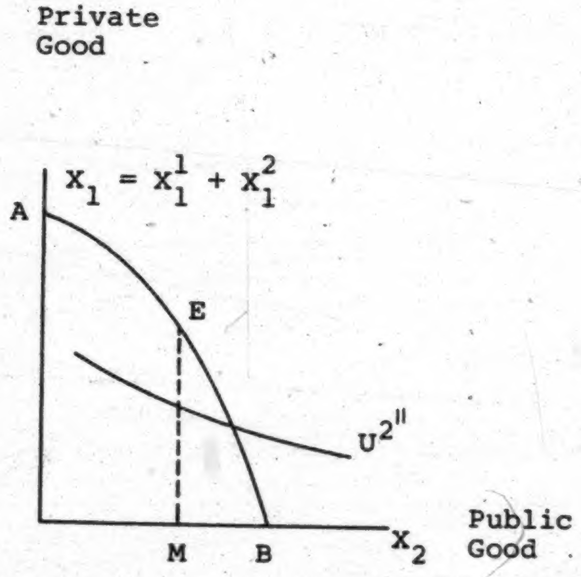

Figure 3 - Production Possibility Curve for Public and Private Goods.

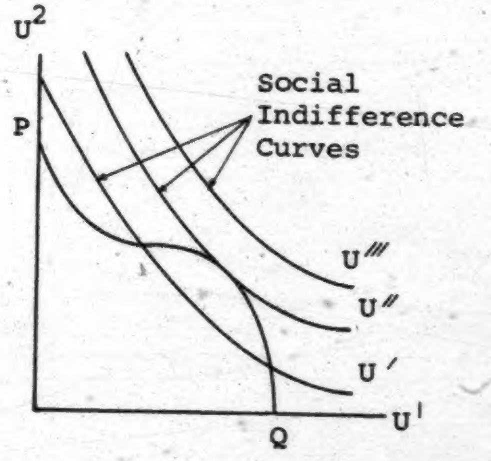

Figure 4 - Utility Frontier of Pareto-Optimal Efficiency Points.

Source: All diagrams were adapted from Samuelson, "Diagrammatic Exposition", (1955), p. 351.

Man 1, and is shown as the curve $p^{1''}$ in Figure 1. Hence, the highest level of utility that Man 1 can attain under these conditions is the tangency point E, where M public goods and L private goods are consumed per time period.

This process is repeated for each of the infinite number of initial indifference curves for Man 2, and the totality of these points defines the utility possibility frontier PQ which is mapped in Figure 4.

If one then makes the heroic assumption that the social welfare function is indeed known, the tangency point of the utility frontier with a social indifference curve yields the same "best" solution as would have been attained by using the mathematical techniques expounded in Samuelson's 1954 article.

Again, however, the crucial point is that this equilibrium will not be attained. Breton reiterates Samuelson's central argument:

> We can now imagine individuals as having two utility functions: one which they keep to themselves and which measures the satisfaction which they derive from public and private goods; and another which they reveal publicly and which measures the amount of public goods they can lead others to believe they desire and with it the "price" which they can "legitimately" be charged. The adoption of such strategies by individuals means that it is not possible for them to know the marginal utility of any given public good to the individuals making up the jurisdiction, it is not possible to devise "prices" which would be equal to those marginal utilities. Governments will have to impose non-benefit systems of taxation to pay for the public goods they supply. Of necessity therefore the "prices" charged will in the case of some individuals be greater than

> the marginal utility they derive from the quantity of a public good supplied, while in the case of other individuals it will be lower.[1]

On the other hand, several authors, notably Bohm, feel that there is a counterbalancing tendency in some cases to overstate one's preferences for public goods, because the benefits from the proposed new good are more readily perceived than the proportion of a recent (all encompassing) tax increase that may be attributed to it.[2] The aforesaid tendency is especially true in the case of welfare recipients and other non-taxpayers: overstatement, not understatement, of preferences is the name of the game.

Breton developed a theory of public expenditure based not on the assumption that governments maximize "the public interest," but rather, on the premise that they maximize the probability of their own re-election.[3] He hypothesized that the propensity to join political activities is proportional to the difference between one's desired and one's actual position with respect to the availability of public goods, and subsequently argued:

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[1] Albert Breton, "A Theory of the Demand for Public Goods," Canadian Journal of Economic and Political Science, XXXII, No. 4 (1966), pp. 463-64.

[2] Peter Bohm, "An Approach to The Problem of Estimating Demand for Public Goods," Swedish Journal of Economics, 73 (1) March, 1971. Bohm develops a questionnaire approach in which the interviewee does not know whether or not he will actually have to pay for the public goods under consideration. It is argued that under these circumstances there is no incentive to state anything other than "true" preferences.

[3] Breton, "Public Goods," p. 455

> . . . an individual's participation in political activity, including voting, will reveal his true preferences for public goods. Indeed, it is at the level of *political activity* and not at that of market activity that the preferences for public goods are made known.[1] (Italics mine.)

Expanding on Samuelson's conclusion that any element of "publicness" in a commodity will lead to a misallocation of resources, Breton asserted:

> It should be observed that even though individuals are in disequilibrium with respect to the supply of public and private goods considered in isolation of the political process, they are in full equilibrium once we take account of their political power which, of course, is always given in terms of the political power of others in society.[2]

Despite the fact that certain groups may have "inordinate" or "unfair" amounts of political power, it would therefore appear that governmental intervention in the market place is as justifiable in the case of goods with "public" characteristics, as in the case of technological externalities.

Pollution Abatement as a Public Good

Breton argued that the two basic objective properties of a public good--namely, indivisibility or jointness of demand, and non-exclusion--both apply to pollution abatement if the "population" under consideration is carefully defined.[1] If one person's enjoyment of a lower ambient SO_2 level does not in any way lessen another's enjoyment of that same "good" and if it is not possible to prevent any person within a well-defined jurisdiction from receiving these benefits, then it would appear that effluent control is, in fact, a public good.

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[1] *Ibid.*, p. 465.

[2] *Ibid.*, p. 466.

Allocational problems may therefore develop, as Barkley and Seckler note:

> The structure of an individualistic society provides strong incentives for rational economic man to conceal his demands for collective goods in the hope that he can satisfy them without having to make sacrifices. He may be able to get a free ride. If a person is asked to contribute time and money to an organization interested in preserving the blue whale, he may think the following: "The $50 that the whale is worth to me may be crucial. But if I give it, there is no assurance that the whale will be saved; if I withhold it, the contribution of Joan Baez and others like her may save it anyway. Therefore, I will not contribute the money. If the organization is not successful, it will be money down the drain; if it succeeds, I will enjoy the benefits anyway. So, I will opt for a free ride (on the backs of contributors)."
>
> This is an element of the problem that is again essentially a breakdown in the feedback mechanism. With an ordinary private good, one either pays the price and gets the good or foregoes the purchase and goes without. This is not true of collective goods. *There is no assurance that paying the price will actually obtain the good for the purchaser. And there is always a chance of obtaining the good even if the price is not paid*.[2] (Italics mine.)

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[1] Albert Breton, "Towards an Economic Theory of Pollution Control and Abatement," *Pollution and Our Environment*, (Ottawa: Queen's Printer, 1966), Vol. III, Article D 29-1.

[2] Paul W. Barkley and David W. Seckler, *Economic Growth and Environmental Decay: The Solution Becomes the Problem*, (New York: Harcourt Brace Jovanovich, Inc., 1972), p. 133.

Similar arguments can be utilized to explain the lack of individual incentives in combatting air pollution. Although damages may be high, (say, $2,000,000), they may be rather evenly dispersed over, say, 1,000,000 people. No single person is affected to the extent that it is advantageous to take individual action, and even though the marginal benefits from collective manoeuvers may far exceed the marginal costs thereof, the "freeloader" problem impedes such a solution.[1]

In summary, then, the problem is twofold. First, air, land, and water will be over-used as waste receptors since (in the absence of controls and well-defined property rights) they carry a zero price. Second, failure to reveal preferences may result in a sub-optimal level of pollution abatement.

Dorfman concludes:

> . . . each individual's incentives induce him to use environmental resources more heavily and to contribute less to protecting them than is socially desirable. It should be emphasized that no malign intent or even blameworthy negligence is involved. It would be silly to stay home from Coney Island just because our presence would make it even more congested. No individual can reduce the prevalence of smog by putting a smog-suppressor on his car. The only meaningful solutions are collective solutions.[2]

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[1] If, however, the affected group anticipates that a larger set of people can be coerced into assisting in the provision of abatement, (e.g. through tax-financed subsidies from a higher level of government), the tendency may then be to overstate damages and preferences. Infra, p. 93.

[2] Robert S. Dorfman and Nancy S. Dorfman, editors, Economics of the Environment: Selected Readings, (New York: W. W. Norton & Company, Inc., 1972), pp. xviii - xix.

Criticisms of the Coase Model

It is now possible, utilizing the combined analytical concepts of externalities and public goods, to re-examine Coase-type models with a view to determining the extent to which they can be used in formulating government policy.

To re-iterate the main conclusion, a Pareto-optimal allocation of resources is attained--given Coase's stringent conditions--irrespective of which party compensates the other. Kneese, for one, has some reservations about this approach.

> The strength of this discussion has been its rather deep examination of the specific allocative effects of externalities under various circumstances . . . . The weakness of this discussion has been that it has dealt with an artificial case, which, unless properly interpreted, lends itself to some highly misleading inferences concerning policy.[1]

Coase's critics appear to be particularly unhappy about the following aspects of private bargaining models:

1. The preoccupation with two-party situations.
2. The assumption that the two adversaries have equal economic power, perfect information, and can engage in costless bargaining.
3. The casual preterition of the difficulties involved in organizing for collective action.
4. Coase's over-emphasis on allocational effects and consequent dismissal of distributional considerations.

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[1] Allen V. Kneese, "Environmental Pollution: Economics and Policy," Papers and Proceedings of the 83rd Annual Meeting of the American Economic Association, Detroit, Dec. 28-30, 1970; published in American Economic Review, May, 1971, pp. 153-154.

Each of these items shall be examined in some detail, since _in toto_ they shed considerable light on the basic economic problems of pollution abatement and therefore provide the necessary groundwork for more complicated (and realistic) environmental models.

The typical two-person examples usually involve bucolic situations of bees producing honey whilst fertilizing apple trees,[1] of cattle trampling crops,[2] or of sparks from railway engines setting farmer's fields ablaze.[3] When these "meaningful examples" are contrasted with real-world pollution problems--such as automobile exhaust fumes, aircraft noise, or pulp mill effluent--the reader cannot help but question the relevance of two-party externality situations. Indeed, given the modern-day pervasiveness of side-effects, such parables appear rather anachronistic from the policy standpoint, except as a reminder of the reciprocal nature of externalities.

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[1] J. E. Meade, "External Economies and Diseconomies in a Competitive Situation," _Economic Journal_, LXII, No. 245 (1952), pp. 54-67. Meade's paper provides a good mathematical discussion of the Pigovian tax-subsidy technique. Although Meade's article is concerned with _favorable_ external economies, it would appear that little more than simple algebraic manipulation would be required to handle unfavorable externalities.

[2] Coase, "Social Cost," pp. 3-8.

[3] _Ibid._, pp. 32-34.

In the real world, there are many sources of pollution and many affected parties, as Kneese notes:

> . . . an analytical orientation which regards externalities as a systematic and pervasive phenomenon in modern economies is much more on all fours with the real situation than one which regards them as a somewhat freakish anomaly which can often, if not usually, be efficiently controlled by ad hoc measures or private bargaining.[1]

With respect to the second criticism of Coase-type solutions, even the most casual empiricism would suggest that the adversaries are far from "equal". Can General Motors and an emphysema victim (or an environmental club) really be considered peers? Does a private citizen have the same resources to prove that an activity is harmful that a large corporation can muster to prove that it is safe? Furthermore, companies occasionally threaten to cease production if more stringent pollution controls are proposed: does anyone have accurate financial information to determine if the company is only bluffing?

The costless-bargaining postulate has also been attacked:

> The important assumption here is that bargaining is costless, that there are no mediators, arbitrators, researchers, or others to reduce the amount of money transferred among the parties to the bargaining process. Because the actual cost of bargaining is not zero and can be very high, actual bargaining to arrange pollution rights will be undertaken only when the increased value

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[1] Kneese, "Environmental Pollution," p. 154.

> of production upon the rearrangement is greater than the costs of bringing it about.[1]

In Mishan's opinion:

> . . . transactions costs act as a formidable cost-barrier, protecting the existing market solution against hypothetical Pareto improvements. But which side of the barrier society starts from is not determined by economic mechanisms. If society chooses its laws so as to place itself on the pollutant-permissive side of the cost barriers, the over-all optimal solution (which may coincide with the existing market solution) will involve more pollution than a costless ideal solution, and more pollution still than the over-all optimal solution that emerges if society, instead, chooses its laws as to place itself on the other side of the cost barrier.[2]

It is also clear that the assignment of the burden of proof may be a paramount issue. Many writers feel that the customary procedure for private litigation wherein the burden of proof is on the plaintiff, (often, a private individual), rather than on the defendant (frequently, a large company)--stacks the cards against those damaged:

> The injury alleged must be actual and demonstrable--something more than mere inconvenience, wounded sensibilities, or speculative or contingent injury. Even if such legally cognizable injury can be shown, the casual relationship between the injury and the defendant's acts may be difficult to establish. This is particularly

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[1] Donald N. Thompson, The Economics of Environmental Protection, (Cambridge, Massachusetts: Winthrop Publishers, Inc., 1973), p. 159.

This would appear to be a necessary, though not sufficient, condition for a re-arrangement to occur. We are still beset, inter alia, with all the problems of organizing for collective behavior.

[2] E. J. Mishan, "Pangloss on Pollution," The Swedish Journal of Economics, LXXII, No. 6 (1971), p. 118.

> true in those cases (probably most) in which the environmental abuse does not produce immediate, apparent injury, but is of a more subtle character--a creeping, cumulative injury that is nonspecific and that may become manifest only over a period of many years or perhaps even generations . . . . And the causal link may be even more difficult to forge where the injury results from environmental abuse stemming from multiple sources and is the product of, or exacerbated by, synergistic effects.[1]

Synergistic (or potentiated) effects occur when the action of two or more different substances acting together produces an effect greater than that of any of the components acting alone, and are, as Green implies, further justification for shifting the burden of proof. For example, the synergistic relationship between SO_2 and smoke is well documented: certain metallic salts found in fly ash hasten the conversion of SO_2 to SO_3, which may penetrate deeper than the upper respiratory tract.[2] Similarly, Carson noted that when malathion was administered at about the same time as certain other organic compounds, a highly-toxic situation was created: 1/100 of the lethal does of each compound could be fatal when the two were combined. This result has also been observed with many other pairs of organic phosphate insecticides--one compound apparently destroys the liver enzyme responsible for detoxifying the other.[3] Therefore, chemicals administered in accordance with separately-determined legal limits can interact with dangerous consequences.

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[1] Harold P. Green, "The Role of Government in Environmental Conflict", in Malcolm R. Baldwin and James K. Page, Jr., Law and the Environment, (New York: Walker, 1970), p. 236.

[2] Alan R. Smith, Air Pollution, Mongraph No. 22 of the Society of Chemical Industry, (London: 1966), p. 135.

[3] Rachel Carson, Silent Spring, (Boston: Houghton-Mifflin Company, 1962), p. 195.

To the economist _qua_ policy maker, synergism has at least three major implications. First, the analysis and prediction of pollution costs--always an imprecise endeavour--takes on even more of a stochastic nature. Second, the effluent standards and/or fees for a particular contaminant cannot be established in isolation of those set for other deleterious substances. And, finally, the already-solid cases for publicly-funded pollution research, and for a gradual shifting of the burden of proof, apply _a fortiori_.

All of the above considerations are important, but the last, in particular, demands elaboration. In all instances, but especially where synergistic effects may be involved, we cannot afford to wait until we have 100% proof that compounds are dangerous before expending resources on abatement. Indeed, the need for new scientific _methodology_ to assess pollution phenomena would appear to be a recurrent theme in the technical and biological literature, and the argument that the concept of "conclusive evidence" must be re-defined to acommodate complex interactions between biological and physical factors is well stated in a U.S. government report:

> We now know that the full effects of environmental changes produced by pollution cannot be foreseen before judgements must be made. The responsible judgement therefore must be the _conservative_ one. Trends and indications, as soundly based as possible, must provide

> the guidelines; demonstration of disaster is not required. Abnormal changes in animal populations, however small, at whatever stage in the life history of the individual, or in whatever niche of the species complex, must be considered warnings of potential hazard.[1]

A "conservative" approach is not necessarily inconsistent with orthrodox cost-benefit techniques if one properly accounts for the disutility of risk, and the attainment of long run welfare maximization may well involve a shifting of the burden of proof to the polluter.

The third impediment to private bargaining is the arduousness of organizing for collective behavior. For example, pulp mill pollution might affect hundreds of people, none of whom finds it worthwhile to bargain, commence litigation, or even obtain information.[2] On the other hand, assembling for group action might be costly, and rational behavior by each separate individual would dictate an understatement of his preferences for pollution abatement: the free-rider effect would therefore prevent the attainment of a Pareto-optimal state. This is clearly a vastly different state-of-affairs than the two-party situations Coase utilized, and Buchanan and Stubblebine, in their devotion to mathematical rigor, pay scant attention to this point when they extend their "affected party" from an individual to an n-person group. Utilizing our previously-developed notation[1] they state:

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[1] U.S., President's Science Advisary Committee, Restoring the Quality of our Environment, (Washington: 1965), cited by Rene Dubos, "Promises and Hazards of Man's Adaptability" in Jarrett, ed. Environmental Quality, pp. 36-37.

[2] Perhaps the most unfortunate aspect of this situation is that no market signal would then be generated to indicate even the existence of external costs.

> We have remained in a two-person world, with one person affected by the single activities of a second. However, the analysis can readily be modified to incorporate the effects of this activity on a multi-person group. . . .
>
> For a multi-person group (A_1, A_2, . . . , An) any one or all of whom may be affected by the activity Y_1, of the single person, B, the condition for Pareto relevance is,
>
> $$(-)\sum_{i=1}^{n} u^{Ai}_{Y_1} \Big/ u^{Ai}_{X_j} > \left[u^{B}_{Y_1} \Big/ u^{B}_{Y_j} - f^{B}_{Y_1} \Big/ f^{B}_{Y_j} \right] ;$$
>
> $$u^{Ai}_{Y_1} \Big/ u^{Ai}_{X_j} < 0.$$[2]

Apparently the "ready-modification" they envisage refers to the simple physical act of inserting extra superscripts and a summation sign into their one-affected-party solution in order to demonstrate the vertical addition of n marginal rates of substitution. In practical applications, of course, the collective good problem is infinitely more complicated, as Thompson indicates:

> If several victims are involved, the freeloader effect will provide disincentives to a bargaining solution. Since air and water are common resources, one victim's payment will produce pollution reduction advantages which also accrue to his fellow victim. Each victim is motivated to do nothing and let others do the bribing. The resultant lack of incentive among all victims prevents any action at all.[3]

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[1] Supra, pp. 14-17.

[2] Buchanan and Stubblebine, "Externality," p. 376.

[3] Thompson, Economics of Environmental Protection, pp. 161-162.

The final aspect of Coase-type solutions to be noted is the casual, somewhat disinterested manner in which distributional effects are dismissed--especially when compared to the zealous pursuit of allocational efficiency. Furthermore, and quite aside from the previously-discussed complications of non-costless (and collective) bargaining; lack of information, with its resultant possibility of bluffing; and, the placing of the burden of proof--all of which can affect the distribution of income--it might be argued that there are also ethical considerations involved in Coase-type solutions. Although this admittedly involves value judgments, (i.e., that polluters are wrongdoers, and that wrongdoers should never, under any circumstances, be bribed to desist), no vote-maximizing politician would fail to take such deeply-entrenched public attitudes into account. Indeed, there is a considerable air of political inexpediency about the "bribery" aspect of private bargaining models, and Mishan provides a pertinent example:

> The fact that a conflict of interest exists does not, however, always preclude judgment about culpability. If a burglar breaks into my house in order to steal my wife's jewelry, and I try to prevent him, there is a clear conflict of interest. For that matter, given the burglar's intention and his appraisal of the effort and risks, an effective bribe to desist may be an overall Pareto optimal solution. Yet it would be hard to conceive of any organized society having difficulty in deciding the rights of such a conflict.[1]

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[1] Mishan, "Pangloss on Pollution," p. 118.

In summary, then, this section has attempted to demonstrate that the determination and attainment of the "best" use of resources can be an extremely complicated matter when environmental pollution is present. Therefore, although Coase's seminal article is important for its revelations of inconsistencies in the Pigovian literature; its clarity in explaining the reciprocal nature of externalities and the resultant allocational effects; and its creation of the impetus for a complete re-thinking of the field of pollution economics; the stringent assumptions which were required to yield his rather startling results would appear to preclude straightforward private bargaining solutions in most practical situations. It is by now clear that pollution is a collective problem that must, by and large, be alleviated by collective action. However, (as the plethora of rebuttals, rejoinders, and rhetoric in the literature on externalities readily attests), the determination of the appropriate nature of the requisite paternalistic intervention can be an extremely complicated matter. Simple solutions work only in simple models: in the real world, with its multiplicity of economic units and complex interrelationships between them, it is infinitely more difficult to determine whether total welfare has, in fact, actually been improved by a specific type of regulation. Indeed, it is only through painstaking economic analysis encompassing all additional costs and benefits that the effects of government intervention may properly be assessed.

CHAPTER III

AN OVERVIEW OF THE TECHNICAL ASPECTS AND REGULATORY FRAMEWORK OF THE SOUR GAS PROCESSING INDUSTRY

Introduction

The purpose of this chapter is to provide the reader with basic background information pertaining to the technical and regulatory aspects of Alberta's sour gas processing industry, to facilitate the environmental economic analysis which follows in Chapter IV. Inasmuch as this information is readily available in depth from other sources, only the most fundamental facts shall be cited, and the interested reader seeking more detail is referred to the bibliography.

Hydrogen sulphide occurs in Western Canadian natural gas in concentrations ranging from trace amounts to about 85 per cent at Panther River, north-west of Calgary.[1] In Alberta it is found primarily in geological formations of Mississippian and Late Devonian Age. Hydrogen sulphide has an extremely unpleasant odor-reminiscent of rotten eggs--which can be detected at concentrations as low as 0.1 ppm. It can be fatal in thirty minutes or less at concentrations of 100 ppm, and at concentrations of 10,000 ppm it is instantly fatal.[2]

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[1] Panther River gas also contains approximately 14 per cent CO_2, and is not being processed. The highest H_2S concentration currently being processed is 53 per cent at Harmattan, near Didsbury.

[2] ERCB, Status of Environmental Protection, p. 3-3

H_2S can also damage plant life, and can cause discoloration of paint and silverware by reacting with lead or other metals to produce dark metallic sulphides.[1] Furthermore, the highly-corrosive nature of this gas, especially when water is present, has been responsible for pipeline failures.[2] It is therefore imperative that all H_2S entering a gas processing system be converted to either elemental sulphur or sulphur dioxide,[3] or else re-injected.[4]

History and Basic Statistics

The early gas plants in Alberta did not recover any elemental sulphur from the hydrogen sulphide in their inlet gas. Instead, the acid gas constituents were simply separated from the hydrocarbon gases and flared. It is estimated that the original Turner Valley Plant, constructed in 1933, released 200 tons of sulphur in the form of SO_2 daily into the atmosphere.[1]

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[1] Ibid.

[2] "Sour Gas Study Needed to Show Line Pipe Failure," Oilweek, March 20, 1972, p. 27.

[3] SO_2 has an odor threshold of 3 ppm, can cause dangerous illness in concentrations above 100 ppm, and is fatal in thirty minutes or less at concentrations above 2000 ppm. Sensitive plants and trees can be damaged if exposed for a few hours to concentrations in the range of 0.3 to 0.5 ppm. ERCB, Status of Environmental Protection, p. 3-2.

[4] This alternative is not currently being utilized in Alberta, due to safety and metalurgical problems and high compression costs. However, gas containing very small amounts of H_2S is reinjected into the Harmattan Elkton formation to enhance the recovery of liquid hydrocarbons. Infra, p. 95.

The first sulphur recovery plant in Alberta was constructed in 1951, at Jumping Pound, north-west of Calgary. It had a designed maximum input capacity of 35 million cubic feet per day (MMCFD) gas, and recovered 30 LT/D sulphur at an average recovery efficiency of 80% through a one-stage Claus unit.[2]

The industry grew rapidly from this rather humble beginning and produced a total of 6.5 million long tons of sulphur in 1972. Today, sixty-three plants in Alberta process sour natural gas, forty-one of which are equipped with sulphur recovery facilities. Total design inlet capacity is 26368 LTD.[3] Average recovery currently exceeds 95%, and will exceed 97% when the enhanced recovery facilities required under the new guidelines are fully operational. Basic plant information is summarized in Table 1.

Three factors contributed to the rapid rise in Alberta sulphur production portrayed in Table 2: pipeline connections which allowed Alberta gas to enter Ontario and

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[1] R. F. Klemm, Environmental Effects of the Operation of Sulphur Extraction Gas Plants. (Edmonton: Environment Conservation Authority, 1972), p. 4.

[2] *Ibid.*, p. 5

[3] Actual recovered tonnage is likely to be only about one-half of this value for the following reasons:
(a) None of the recovery facilities are 100% efficient.
(b) Plants are periodically shut down for remedial work such as catalyst changes.
(C) Many plants do not produce sales gas, and hence sulphur, near peak capacity except during the winter.

Table 1

BASIC PLANT INFORMATION

Plant, Operator and Location	Year Built	Design Inlet Capacity Long Tons/Day[1]	Minimum Recovery Required %	Status[2]
CATEGORY I (4,000 to 1,000 LT/D)				
Ram River, Aquitaine, S 1/2 2-37-10 W5	1972	4,176	98.0	Complies
Kaybob S III, Chevron, S 1/2 15-58-19 W5	1971	3,572	98.0	Complies
Waterton, Shell Canada, 20-4-30 W4	1962-71	3,098	98.0	Remedial work in progress, completion early 1975.
Kaybob I and II, HBOG, 1 & 2-62-20 W5	1968-69	2,181	98.0	Remedial work in progress, completion early 1975.
Windfall, Texasgulf Amoco, 17-60-15 W5	1961	2,020	98.5	Remedial work in progress, completion early in 1975.
Balzac, Petrogas, 2-26-29 W4	1961	1,930	98.0	Facilities application filed, awaiting approval.
Crossfield East, Amoco, 14-28-1 W5	1965	1,800	98.0	Facilities application filed, awaiting approval.
CATEGORY II (1,000 to 400 LT/D)				
Strachan, Gulf Oil Canada, 34-37-9 W5	1971	955	97.0	Complies
Jumping Pound, Shell Canada, 13-25-5 W5	1951	530	96.0	Complies

Table 1 (continued)

Plant, Operator and Location	Year Built	Design Inlet Capacity Long Ton/Day[1]	Minimum Recovery Required %	Status[2]
Harmattan, Canadian Superior, 34-31-4 W5	1966	508	95.0	Complies
Okotoks, Texasgulf, 27-20-29 W4	1959	451	94.0	Awaiting exemption decision.
Coleman, Saratoga Processing, 11-8-5 W4	1962	406	93.0	To file for higer recovery.
CATEGORY III (400 to 100 LT/D)				
Olds, Amerada Minerals, 18-32-1 W5	1964	398	96.0	Complies
Bigstone, Amoco Canada, 10-61-22 W5	1968	395	96.0	Complies
Wimborne, Mobile Oil Canada, 12-34-16 W4	1964	358	95.0	Complies
Rimbey, Gulf Oil Canada, 5-44-1 W5	1961	346	94.5	Complies
Nevis, Gulf Oil Canada, 33-38-22 W4	1956	304	95.5	Complies
Quirk Creek, Imperial Oil, 4-21-4 W5	1971	302	95.0	Awaiting decision on compliance application.
Edson, HBOG, 11-53-18 W5	1965	299	93.7	Complies
Lone Pine Creek, HBOG, 23-30-28 W4	1966	250	96.0	Complies

Table 1 (continued)

Plant, Operator and Location	Year Built	Design Inlet Capacity Long Tons/Day[1]	Minimum Recovery Required %	Status[2]
Nevis North, Chevron, 22-39-22 W4	1959	264	97.5	Complies
Simonette, Shell Canada, 6-63-25 W5	1969	276	95.0	Complies
Burnt Timber, Shell Canada, 13-30-7 W5	1970	208	94.0	Complies
Pincher Creek, Gulf, 23-4-29 W4	1957	196	94.0	Complies
Wildcat Hills, Petrofina, 16-26-5 W5	1961	188	92.5	Complies
Innisfail, Shell Canada, 3-35-1 W5	1960	169	94.5	Complies
Lone Pine Creek, Can Sup., S 1/2 27-29-28 W4	1971	159	95.0	Complies
Rainbow, Aquitaine, 10-109-8 W6	1968	147	93.0	Awaiting decision on compliance application.
CATEGORY IV (100 to 10 LT/D)				
Brazeau River, HBOG, 12-46-14 W5	1969	99	92.0	Complies
Carstairs, Home Oil, 3-30-2 W5	1960	70	90.0	To file for compliance
Sturgeon Lake South, HBOG, 1-69-22 W5	1969	67	93.0	Complies

Table 1 (continued)

Plant, Operator and Location	Year Built	Design Inlet Capacity Long Tons/Day[1]	Minimum Recovery Required %	Status[2]
Nordegg River, Tenneco, 10-44-12 W5	1970	45	90.0	Complies
Minnehik-Buck Lake, CanDel, 5-46-6 W5	1961	35	92.0	Complies
Joffre, Imperial Oil, NE 17-39-26 W4	1972	30	90.0	Complies
Redwater, Imperial Oil, 26-57-21 W4	1956-72	29	92.0	Complies
Caroline, HBOG, 20-34-4 W5	1968	24	90.0	Awaiting decision on compliance application.
Gold Creek, Atlantic Richfield, 26-67-5 W6	1970	22	93.0	Complies
Sylvan Lake, HBOG, 32-37-3 W5	1965	17	90.0	Complies
Bonnie Glen, Texaco, SW-17-47-27 W4	1974	15	92.0	Complies
Turner Valley, W. Decalta, 6-20-2 W5	1933	15	86.0	Complies
Black Diamond, Sun Oil, 10-12-19-2 W5	1972	14	93.0	Complies

[1] Includes facilities under construction for scheduled completion during 1974.

[2] Status after exemption decision, where applicable.

Source: Oilweek June 3/74, p. 28.

TABLE 2

ALBERTA SULPHUR PRODUCTION STATISTICS

Year	Production-- Thousands of Long Tons	Sales-- Thousands of Long Tons	Value of Sales-- Thousands of Dollars	Average Price-- $/Long Ton
1963	1,228	1,044	12,108	11.60
1964	1,414	1,520	16,790	11.04
1965	1,538	1,738	24,122	13.88
1966	1,676	1,727	37,225	21.56
1967	2,116	2,135	64.951	30.42
1968	2,990	2,209	76,318	34.54
1969	3,654	2,568	58,926	22.94
1970	4,182	3,072	27,435	8.93
1971	4,486	2,672	19,284	7.22
1972	6,548	3,106	17,738	5.71
1973	7,800	3,522	18,385	5.22

SOURCE: 1963-1972:ERCB.
1973:*Oilweek*, Jan. 21, 1974, p. 15 (Forecast utilizing ERCB Data).
Estimated Inventory at Dec. 31, 1973 was 12,000,000 Long Tons.

U.S. markets, and which resulted in the exploitation of gas fields containing ever-increasing concentrations of H_2S; a higher environmental awareness, which was partly reflected in higher recovery efficiencies; and a relatively brief but zealous search for high H_2S fields during the mid-1960's due to temporarily high sulphur prices.[1]

Technical Aspects of Sour Gas Processing

The resistance of gas plant operators to the new sulphur recovery guidelines, as attested by the numerous applications for exemption therefrom, was based upon the then-prevailing extremely low price of sulphur, coupled with the well-established technological principle of rapidly diminishing returns[2] in sulphur recovery operations. Therefore, an understanding of the basic technology of the industry is an essential prerequisite to an assessment of the economic difficulties which individual processors--operating within the partial equilibrium framework--claimed the guidelines were precipitating.

A Claus sulphur conversion process or modification thereof is employed in the recovery of sulphur from sour natural gas.[1] Although the basic technique employed is similar from plant to plant, it must be emphasized that each sour gas processing facility is "tailor-made," to accommodate its own unique set of engineering parameters such as H_2S concentration, acid gas quality, etc.

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[1] A fourth factor--improved technology--is a function of the other three.

[2] Once a certain recovery level has been attained, equal increments in expenditures on enhanced recovery lead to ever-decreasing increments of sulphur. See P. Bonnifay and R. Dutriau "Improving Claus Recovery with IFP Process," Gas Processing/Canada, Jan./Feb., 1972, p. 38, for elaboration.

Sour natural gas from the source field first enters an inlet separation facility where salt water and heavy liquid hydrocarbons are removed from the gas by gravity. Any hydrogen sulphide dissolved in the water is stripped out and either flared to SO_2 or directed back to the plant for further processing. The condensate from the inlet separator is sent to a stabilization facility which removes light hydrocarbons and sour gases from the heavier condensate to produce pentanes plus. These vapors are usually compressed and directed to the gas treating plant for sweetening.

The sour natural gas is drawn off the top of the separator and enters a scrubbing tower which contains an aqueous solution of either mono-ethanolamine (MEA), di-ethanolamine (DEA), potassium carbonate, or sulfinol. This treatment solution, the exact composition of which depends in part upon the ratios of H_2S to CO_2 in the inlet gas, absorbs the acid gas constituents. The sweetened gas exits from the tower and is dried in preparation for transmission to pipelines or re-injection to the reservoir. The "rich" amine solution (saturated with CO_2 and H_2S) is heated under decreased pressure in a solvent regenerator. A vapor containing H_2S and CO_2 is liberated and the regenerated amine solution can be used, after cooling, in another scrubbing cycle. The wet acid gases thus accumulated are cooled, dried, and directed to the Claus sulphur recovery plant at a very low pressure. The hydrogen sulphide is burned in a "front end furnace" in a deficiency of oxygen (air) to produce sulphur dioxide which will subsequently react with unoxidized H_2S to yield sulphur.

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[1] For a more detailed discussion of the Claus method than space herein permits, see Klemm, Environmental Effects, pp. 14-33, or P. R. Cote, Canadian Elemental Sulphur from Sour Natural Gas, (Ottawa: Information Canada for Department of Energy, Mines and Resources), Mineral Bulletin MR 121, pp. 11-14.

A complex reversible chemical reaction takes place, and correct proportions of the gases, as well as exacting temperatures, must be carefully maintained. Klemm[1] cites the following three equations as being a very simplified, though essentially correct, version of the reactions:

$$2H_2S + 3O_2 \rightleftharpoons 2SO_2 + 2H_2O$$
$$2H_2S + O_2 \rightleftharpoons 2S + 2H_2O$$
$$2H_2S + SO_2 \rightleftharpoons 3S + 2H_2O$$

In addition, H_2, SO_3, COS and CS_2 may be formed. The latter two compounds, which may be present in the inlet gas, or may be formed in the front-end furnace due to a reaction between H_2S and CO_2, are of particular importance. They are extremely difficult to convert to sulphur, except with expensive catalysts, and either accumulate in the amine solution or are incinerated to SO_2--thereby placing a limit on ultimate sulphur recovery. In recognition of this fact, both the Alberta and British Columbia regulations provide for more lenient recovery efficiencies when CO_2 constitutes a significant proportion of the acid gas.

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[1] Klemm, Environmental Effects, p. 22.

The gas from this furnace is then cooled in a condensor which recovers most of the sulphur vapor. The residual gas is then reheated and enters a catalytic converter where, in the presence of bauxite or activated alumina, more SO_2 and H_2S will react to form additional sulphur which can be recovered in a second condensor, and the process is essentially repeated until about 96% of the sulphur in the original gas stream has been removed.

As many as four stages of catalytic conversion may be utilized, and the gas from the last condensor[1] flows through a coalescer for removal of more droplets of liquid sulphur and then to an incinerator where it is burned with sufficient air and fuel gas to ensure complete oxidization of all the residual sulphur-containing compounds. The products of the final combustion are released to the atmosphere at a temperature of about 1000°F through a stack of height sufficient to ensure that the ensuing dispersion of SO_2 is in accordance with the ambient standards to be enunciated later in this chapter.[1]

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[1] Most authorities, including the ERCB, do not believe that this process can consistently attain the 98 or 99 per cent recovery required for the larger plants under the new guidelines, and that some form of "tail gas cleanup" is therefore necessary. Very complex chemical reactions and technology are involved--a discussion of which is beyond the scope of this paper. However, a summary and comparison of twenty different specialized techniques can be found in J. B. Hyne, "Review and Comparison of Desulphurization Techniques", Gas Processing/Canada, November-December, 1972, pp. 18-32.

Liquid sulphur from all condensers and converters is pumped to storage blocks where it is allowed to cool and solidify, or to "slating" facilities where small discrete slates of elemental sulphur (approximately 2" x 3" x 1/4") are formed.[2]

On July 1, 1972, the Port of Vancouver passed a regulation stipulating that, due to the severe dusting problem caused by the loading of bulk sulphur, only the slated form would thereafter be acceptable for handling within its jurisdiction. At the present time, however, only five plants in Alberta have slating facilities, representing in total a production capacity of 9000 LT/D, 34 per cent of total Alberta sulphur capacity.[3] This accumulation of unusable bulk sulphur, coupled with, and partly the result of, a lack of adequate transportation facilities is presently having the effect of causing western Canadian sulphur to be in fairly short supply at a time of rising prices.

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[1] The airborne SO_2 is either photo-chemically oxidized to SO_3 and thence hydrated to sulphuric acid, or catalytically oxidized to sulphate salts. Klemm, Environmental Effects, p. 47.

[2] See Sulphur (100), May/June, 1972, pp. 24-27 for a detailed description of the slating process.

[3] Werner Wenzel, Alberta Department of Industry, Trade and Commerce, personal interview, August, 1974.

The Regulatory Framework

Although Chapter II repeatedly emphasized the fact that pollution abatement is a collective issue, no mention was made of a mechanism through which the desired level of pollution control could be attained. One common procedure consists of the establishment of a government-sponsored regulatory body (or bodies) to specify and enforce environment standards. The behavior of such a "commission" is, in general, influenced by many factors, including: the overall philosophy of the ruling party, and, in particular, its most dominant members; the relative strengths of political pressure organizations such as environmental study groups, intra-industry associations, the civil service, and citizens' committees; economic considerations, such as employment and supply-demand conditions in key industrial sectors; and advances in scientific documentation and abatement technology. The purpose of this section, then, is to comment briefly on the evolution and duties of Alberta's regulatory agencies, and to enumerate the specific standards applicable to the sour gas processing industry.

The Oil and Gas Conservation Act came into effect on July 1, 1938, and provided for the establishment of the Petroleum and Natural Gas Conservation Board, which was later to be renamed the Oil and Gas Conservation Board (OGCB). Although the primary function of the OGCB was to prevent wastage of these resources, some of its early regulations also had environmental overtones. For example, surface casing was required for blow-out control and ground water protection; restrictions were placed on the dispersal of salt water; and the flaring of sour gas to SO_2 was made mandatory.[1] Legislation passed in the 1950's made Board approval of all aspects of major oil and gas projects--including their conservation techniques and environmental controls--a necessity. During the same decade, the Department of Health developed regulations to control water pollution from gas plant operations, and in 1961 also issued air pollution regulations.

Ammendments, passed in 1970, empowered the OGCB to make regulations pertaining to the control of pollution, and in 1971 this Board was superceded by the ERCB which regulates not only oil and gas but also coal, hydro, and other energy resources. In the same year the Department of the Environment Act, the Environment Conservation Act, The Clean Air Act, and the Clean Water Act were all passed. Statutory amendments in 1972, while confirming the ERCB's general role in environmental protection, asserted that the ultimate authority and responsibility in all such matters rested with the Minister of the Environment.[1] For example, requests for exemptions from sulphur recovery guidelines are evaluated by a team of experts at the ERCB and their recommendations are then forwarded to the Department of the Environment for final approval. An apparent advantage of this approach is the assurance of standards and decisions within the oil and gas sector that are, (to the extent that inter-industry analogies are meaningful), consistent with those in other facets of the Alberta economy.

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[1] ERCB, Status of Environment Protection, p. 1-2.

Nature of the Regulations

The joint objectives of the Department of the Environment and the Energy Resources Conservation Board with respect to controlling sulphur dioxide pollution from sour gas processing operations have recently been explicitly re-stated:

1. The long term total volume of sulphur dioxide emitted to the atmosphere should be controlled and minimized to the extent practicable.

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[1] Day-to-day environmental functions of the ERCB include: drafting regulations, advising on plant approvals, checking operators' charts and reports, inspecting field operations, and ordering and enforcing remedial work. The ERCB has the power to shut down any operation if remedial work is nor completed within a specified time period, and may immediately shut down any operation that it considers to be causing serious pollution--due to plant malfunctioning.

2. The emission of sulphur dioxide to the atmosphere should be in a manner such that there are no adverse effects to the health and welfare of human, animal, and plant life, or public property.[1]

Recovery Efficiency

The first objective is pursued through Sulphur Recovery Efficiency Guidelines laid out in an earlier Letter and reproduced in Table 3. The acid gas qualities are normally defined using the hydrogen sulphide concentrations given below:

Quality	Mole per cent H_2S in Acid Gas[2]
Favourable	60 - 100
Average	40 - 60
Unfavourable	0 - 40

In addition to recognizing the detrimental effect of CO_2 on recovery efficiency, the guidelines also permit the considerable design and operating flexibility necessitated by the unique set of technical parameters existing at each plant. However,

> . . . the Department and the Board are not prepared to approve the construction and operation of sour gas processing facilities unless they are generally satisfied that the design and proposed operating procedures are such that they could expect that both the sulphur recovery requirement and the ambient air quality standards would be met 100 per cent of the time.[3]

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[1] Energy Resources Conservation Board, "Sulphur Recovery and Sulphur Dioxide Emissions at Gas Processing Plants", Informational Letter No. IL-OG 74-5 (Calgary: March 20, 1974), p. 1.

[2] *Ibid*., p. 7.

[3] *Ibid*., p. 3.

Table 3

MINIMUM SULPHUR RECOVERY EFFICIENCY GUIDELINES

(Inlet Rate LT/day)	Required Recovery Efficiency for Various Acid Gas Qualities		
	Favorable	Average	Unfavorable
1000-4000	98-99	98-99	97-99
400 to 1000	96-98	95-98	94-97
100 to 400	94-96	93-95	92-94
10 to 100	93-94	92-93	90-92

Source: Energy Resources Conservation Board, "Sulphur Recovery Requirements: Gas Processing Operations," Informational Letter, No. IL-29, (Calgary: November 9, 1971), Attachment 1.

For this reason, further elaboration on the type of facilities normally required to achieve the recovery objectives has been distributed to all operators. (See Table 4.)

As noted earlier, many operators found the required investment in enhanced recovery facilities "uneconomic," inasmuch as the expected incremental abatement expenditure was not fully offset by anticipated incremental returns from the sale of sulphur. They therefore availed themselves of their privilege of applying for an exemption from the guidelines, and the decisions pertaining to several such requests are discussed in the following chapter.

Ambient Air Quality Standards

Although the establishment and enforcement of high sulphur recovery standards is extremely useful as a means of restricting total long term SO_2 emissions, it does not necessarily follow that all environmental damage is thereby avoided. The residual sulphur-bearing compounds must be burned to SO_2, and the concentration of this substance in the incinerator stack may exceed 10,000 ppm. Since SO_2 levels as low as 0.3 ppm for short periods may cause damage, rapid dispersion is essential. The regulatory agencies have therefore specified minimum standards for both stack gas exit temperature and stack height.[1] These standards are based

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[1] The most recent criteria for both incineration and flare stacks may be found in ERCB, IL-OG 74-5, Attachment 1.

Table 4

RECOMMENDED SULPHUR PLANT CRITERIA

Facilities normally considered necessary to achieve the required sulphur recovery efficiency are given below.

Required Recovery Efficiency	Acid Gas Quality		
	Favourable	Average	Unfavourable
90 - 92	2 stage Claus	2 stage Claus	2 stage Claus
92 - 94	2 stage Claus	2 stage Claus	3 stage Claus
94 - 95	2 stage Claus	3 stage Claus	3 or 4 stage Claus
95 - 96	3 stage Claus	3 or 4 stage Claus	4 stage Claus or TGU
96 - 97	3 or 4 stage Claus	4 stage Claus or TGU	TGU
97 - 98	4 stage Claus or TGU	TGU	TGU
98 - 99	TGU	TGU	TGU

NOTE: (a) TGU means a Claus plant followed by tail gas clean-up facility or equivalent process.

(b) Departure from the recommended guidelines above would have to be adequately documented to provide evidence that the required sulphur recovery efficiencies will be achieved.

Source: ERCB IL 74-5, Attachment 2.

upon complex engineering formulae and normally permit the attainment of the ambient levels to be enumerated presently. However, the complex meteorological and terrain conditions which characterize the location of many gas plants has necessitated further research into plume dispersal.[1]

In January, 1973, the Department of the Environment issued a Ministerial Order specifying maximum permissible levels for the following containmants: sulphur dioxide, hydrogen sulphide, oxides of nitrogen (as equivalent nitrogen dioxide), carbon monoxide, total oxidants (as equivalent ozone), suspended particulates, and-making due allowance for normal background levels--total dustfall.[2]

The regulations with respect to SO_2 and H_2S are reproduced below; the bracketed figures following each time period denote the equivalent standard expressed in parts per million by volume:

> Sulphur dioxide in the ambient air shall not exceed an average maximum permissible concentration of

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[1] For elaboration and suggestions, see Alberta, Environment Conservation Authority, Environmental Effects of the Operation of Sulphur Extraction Gas Plants in Alberta: Report and Recommendations, (Edmonton: 1972), pp. 44-45. It is obviously impossible to continuously monitor every site that may be subject to SO_2 emissions, and sometimes even quite difficult to predict which locations should be monitored. For this reason continued and increasing emphasis on continuous monitoring of stack emissions can be expected, in addition to extra monitoring of ambient levels.

[2] Government of the Province of Alberta, "Clean Air (Maximum Level) Regulations," Alberta Regulation 10/73 (Edmonton: Queen's Printer, 1973).

(a) 30 micrograms per cubic meter as an annual arithmetic mean: - (.01 ppm)

(b) 150 micrograms per cubic meter as a 24 hour concentration: - (.06 ppm)

(c) 450 micrograms per cubic meter as a one hour concentration: - (.17 ppm)

(d) 525 micrograms per cubic meter as a half hour concentration: - (.20 ppm)

Hydrogen sulphide in the ambient air shall not exceed an average maximum permissible concentration of

(a) 4 micrograms per cubic meter as a 24 hour concentration - (.003 ppm)

(b) 14 micrograms per cubic meter as a one hour concentration: - (.010 ppm)

(c) 17 micrograms per cubic meter as a half hour concentration: - (.012 ppm)[1]

The SO_2 standard most frequently cited is 0.20 ppm at ground or tree top level on a one-half hour basis. This standard now applies to the entire province. However, prior to the issuance of Alberta Regulation 10/73, permissible level was 0.2 ppm at ground level in populated and agricultural areas, and 0.3 ppm in all other areas, determined at either tree top level or ground level as circumstances warranted.[2] Hence the trend in this case has been towards uniformity of standards.

At first glance, it might appear that the establishment of air quality standards for hydrogen sulphide is inconsistent with the requirement that this compound be entirely converted to sulphur dioxide. However, there are many ways in which small quantities of hydrogen sulphide can be released to the atmosphere, if inadequate precautions are taken. These include: incomplete combustion of H_2S during flaring necessitated by unusual operating conditions, corroded pipelines or fittings; release of entrained H_2S from liquid sulphur, and stock tank vapors.[1]

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[1] *Ibid.*, Part 1, Sections 2 and 3. The conversions to ppm were obtained from Mr. R. Dunbar of the ERCB.

[2] ERCB, *Status of Environment Protection*, pp. 6-9.

Other Contaminants

The complex nature of sour gas processing necessitates the utilization of numerous solvents, coolants, lubricants, additives, catalysts and desicants. These substances eventually become somewhat contaminated and their subsequent disposal presents a potential for water, soil and/or air pollution, thereby necessitating close scrutiny by the regulatory agencies. The problem presented by these auxiliary pollutants has been expanded upon by Klemm, who is particularly concerned about emissions from burn pits and flare stacks, since the apparent incomplete combustion may generate a variety of oxygenated hydrocarbons similar to those which characterize urban smog.[2] Burn pits and flare stacks have been responsible for many complaints in the past, since their mephitical emissions are of much more pressing concern to the local citizens than, say, the long run effects of low level air pollution. Fortunately, these, and other pollution problems not directly related to SO_2 emissions, can often be alleviated relatively inexpensively with proper equipment and the good operating procedures stipulated in other regulations. Indeed, one of the requests for a sulphur recovery exemption was granted on the proviso that all other forms of pollution from operations be remedied.

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[1] For elaboration, see: Environment Conservation Authority, Report and Recommendations, pp. 54-65.

[2] Klemm, Environmental Effects, Part 6.

CHAPTER IV

APPLICATIONS OF ECONOMIC THEORY TO POLLUTION ABATEMENT IN THE SOUR GAS PROCESSING INDUSTRY

Introduction

Having developed the economic theory of pollution abatement and having briefly discussed the basic structure of the Alberta sour gas processing industry, it is now possible to attempt to assess the environmental aspects of the aforesaid industry within the general framework of social cost-benefit analysis. To this end, a simplified benefit-cost model is described, primarily for the purpose of defining terms and for demonstrating that the socially optimal level of pollution is not, in general, the zero level. Following this, the existence of technical externalities, and, hence, discrepancies between private and total costs and benefits is empirically demonstrated through reference to litigation arising from gas plant operations in south-western Alberta. Next, the fact that gas plant operators are, in general, being required to invest considerably more in abatement equipment than documented damages would appear to dictate is analysed in terms of "hidden" pollution costs. And finally, the extent to which these extra costs are recognized in the revised ERCB definitions of "economic sulphur recovery" is discussed.

The Benefit-Cost Framework

The purpose of this short section is to precisely define the terms "cost" and "benefit" as they are used in economic studies of pollution and pollution abatement, and to show how these definitions can be utilized in a simple graphical demonstration of the optimum level of pollution abatement.[1]

Ridker proposes the following terminology:

1. Cost of Control: The cost of all changes necessary to bring about a given alteration in air quality.
2. Benefits of Control: All the consequences of this alteration. This may also be referred to as the "Cost of Pollution," since it represents benefits foregone in the absence of controls.[2]

Ridker then develops a set of graphs portraying the cost of pollution and the cost of control as functions of the level of pollution.

The Total Cost of Pollution (TCP) curve is shown with a positive P intercept (P_1) to demonstrate the hypothesis that there is a threshold level of pollution below which damages are thought to be zero. (This assumption is probably not universally valid. For example, some scientists feel that there is no "safe" dose of radiation). The accelerating upward slope of the TCP curve demonstrates the notion of increasing marginal costs: presumably, the slope approaches infinity when many human lives are endangered.

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[1] For a more detailed description of the entire field of cost-benefit analysis as it relates to the public sector, see Roland N. McKean, Efficiency in Government Through Systems Analysis, (New York: John Wiley and Sons, Inc., for the Rand Corporation, 1958).

[2] Ronald G. Ridker, Economic Costs of Air Pollution: Studies in Measurement, (New York: Frederick A. Praeger, Publishers, 1967), pp. 1-11. To complete the duality, perhaps the first term could also be facetiously referred to as "benefits of pollution", since the abatement costs could be saved if anti-pollution regulations were removed.

The Total Cost of Control (TCC) curve is negatively sloped since low levels of pollution imply high levels of abatement (given the initial environment and level of production) and hence high cost.[1] The curve is convex to the origin, implying that equal increments in the level of abatement lead to increasing increments in abatement costs.

The probably well-founded concept of increasing marginal costs of control and pollution is portrayed in Figure 6.

The intersection of MCC and MCP determines the "optimal level of pollution."[2] At a different level of pollution, say P_4, the marginal cost of pollution (i.e., the marginal benefit from control) exceeds the marginal cost of control and hence it would be desirable to increase

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[1] A similar series of graphs may be developed by measuring the level of pollution abatement on the horizontal axis. In this event, the slopes of the TCC and TCP curves, as well as those of their "marginal" analogues, are reversed.

[2] The value of recovered sulphur is a benefit of abatement, and, therefore, a cost of pollution. An $x increase in the price of sulphur will shift the MCP upward by a like amount--thereby lowering the optimum level of pollution.

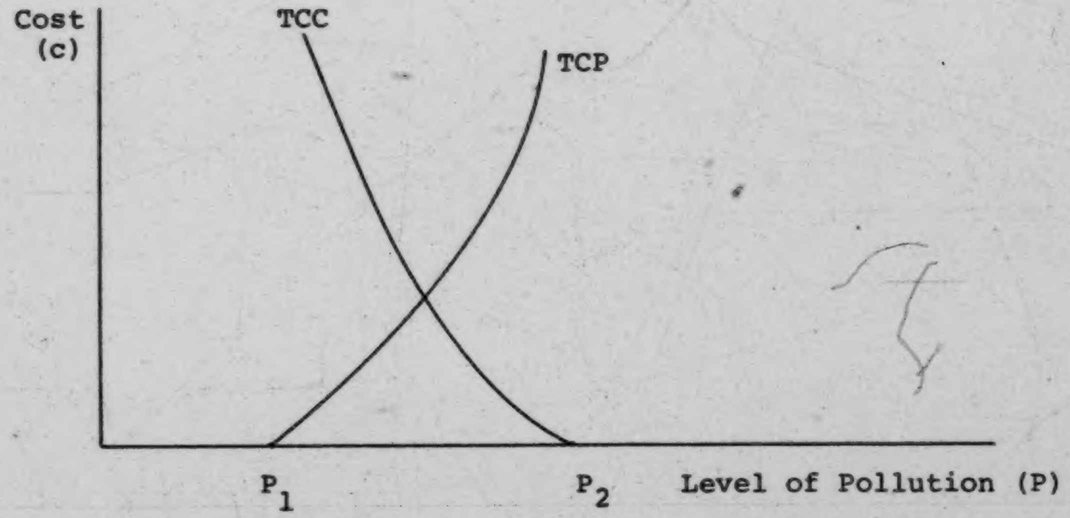

Figure 5-Total Costs of Pollution and Control.
Source: Ridker, Economic Costs, p. 5.

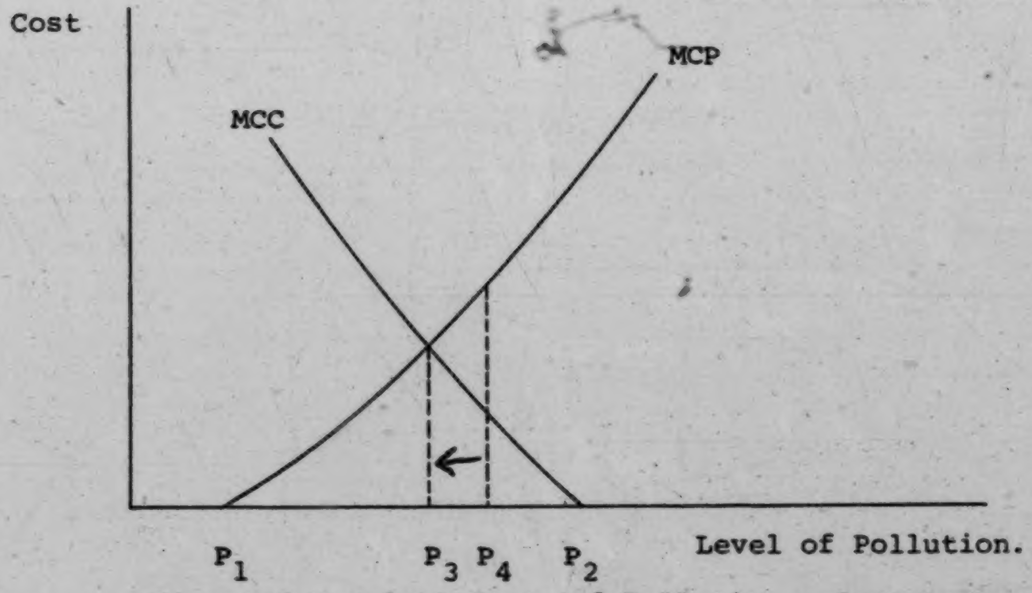

Figure 6-Marginal Costs of Pollution and Control.
Source: Ibid.

the level of abatement, i.e., to move towards P_3. (A similar, reverse, argument applies if one starts to the left of P_3). Again abstracting from the difficulties of actual quantification, this result is in accordance with the welfare-maximizing dictum MTB = MTC.

Figure 7 is a vertical summation of TCC and TCP curves.[1] The level of pollution that minimizes total cost is again P_3.

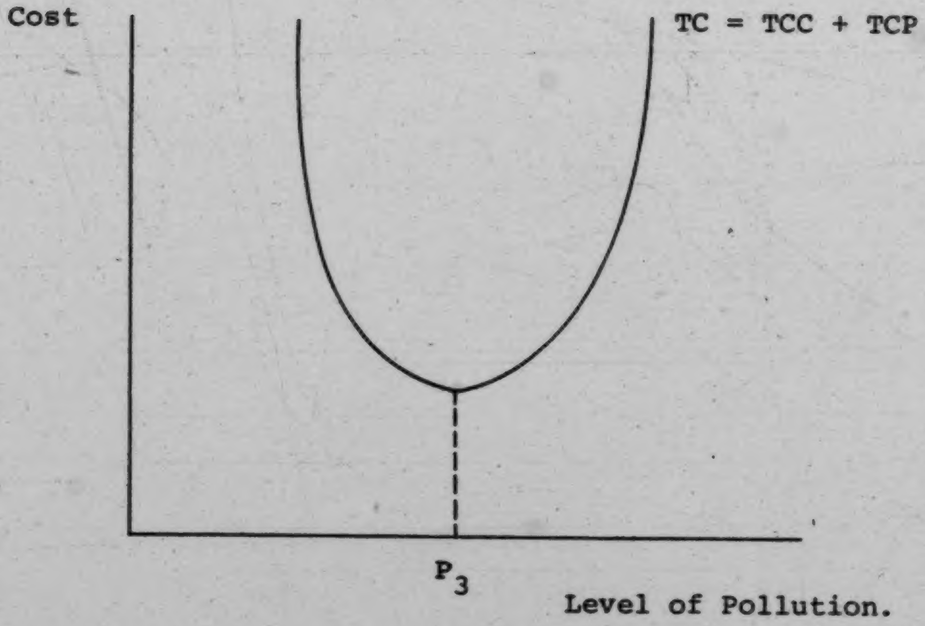

Figure 7-Summation of Total Costs of Pollution and Pollution Control.
Source: Ibid.

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[1] Although the TC curve is likely to be U-shaped, it is not, in general, symetrical.

Discussion of the Model

Although Ridker's model is beneficial for resolving the semantic problems which occasionally occur in the economic literature on pollution, for emphasizing the "incremental" approach which characterizes rational economic decision-making, and for illustrating the total-cost minimizing level of pollution, (which tautologically corresponds to the total-cost minimizing level of pollution abatement), it cannot, unfortunately, be applied in the same relatively straightforward manner that cost-benefit analysis is utilized in private sector capital budgeting decisions.

The typical "private" solution in the petroleum and natural gas industry often involves little more, in principle, than comparing the initial investment outlay for productive equipment with the present value of anticipated net cash flows. It is then possible to assess alternative investment proposals by comparing their net present values, benefit-cost ratios, or internal rates of return.[1]

The principal sources of error therefore lie in the estimation of initial investment outlays and in the forecasting of future revenues and costs. Without underestimating the formidability of accurately determining these values, particularly when the project life span is long, one may nevertheless assert with some confidence that the decision making process is much more complex in the public sector. Indeed, the road to welfare maximization through rational economic analysis is "booby trapped" with a plethora of conceptual and pragmatic problems, including: the indeterminacy of the social welfare function; the effects of various proposals on the ultimate distribution of income and stability of the macroeconomy; the definition, and subsequent inclusion or exclusion, of so called "secondary benefits"; and, the actual quantification of external effects, many of which are by their very nature stochastic and intangible. Although a moment's reflection, (even without further supporting detail), suffices to affirm the relevance of all of these complications to gas plant pollution, the last consideration demands particular attention.

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[1] A good conceptual and practical discussion of capital budgeting may be found in J. Fred Weston and Eugene F. Brigham, Managerial Finance, 4th Edition, (New York: Holt Reinhart and Winston, Inc., 1972), Chapter 7. The authors demonstrate that the three approaches do not always yield consistent rank orderings, and argue that the NPV method is usually preferable.

Quantification of external costs--even at a constant level of pollution--is a most formidable task, due to: the obscure, transient nature of many types of damage; the tremendous variation in individual susceptibilities; the extreme difficulty of determining whether or not the affected party has made the optimal, damage-minimizing, adjustment to the environmental disruption; and, the arduousness of eliminating the effects of other causative variables when ascertaining the specific amount of total damage attributable to pollution. Furthermore, straightforward application of the MCC=MCP criterion necessitates the determination of a damage function over the entire (relevant) domain of pollution levels. Such undertakings are clearly beyond the scope of this paper: however, a summarization of a portion of the information that has already been collected may be beneficial in obtaining some insight into the nature and extent of damages alleged to have been caused by sour gas processing, and may, in fact, provide the basis for a "first-order" attempt to assess whether too much or too little is being expended on pollution abatement.

The Pincher Creek Litigation: Background Information

The history of actual litigation arising out of sour gas operations in southwestern Alberta constitutes, in effect, the most concerted attempt to specify damages and therefore provides a convenient starting point for economic analysis.

Sour natural gas was discovered in the Pincher Creek region of the extreme south-western corner of the province in the late 1940's, and by 1957 The British American Oil Company Limited had constructed a gas processing plant with sulphur recovery facilities. A second plant was installed in the same general area by Shell Oil Canada Ltd. in 1962. Due to the pioneering nature of these projects and the presence of emission standards less rigidly codified and enforced than those which prevail today, operating and testing techniques were inadequate to prevent the release of solid, gaseous, and aqueous substances to the environment in quantities that were sufficiently large to provoke many complaints from residents in the proximity of the plants. The allegations, to be expanded upon shortly, included physical discomfort, agricultural damages, and accelerated corrosion. The affected citizens felt that the gas plants were not taking sufficient means to remedy the situation, and in 1963 seventeen families formed the Pincher Creek Industrial Research Pollution Committee to pressure the government into taking appropriate corrective action. Dissatisfaction with the government's lack of co-operation, and dismay with its thinly-veiled scepticism that a problem even existed, led to the Committee's initiation of a law suit against B.A. and Shell which dragged on for more than half a decade. Each of the affected families sued on their own behalf for specific damages as well as for general damages and costs for each member of the family.

The companies categorically denied all allegations, stating that noxious gases were not being discharged, and that even if they were--which was denied--the quantities emitted thereof were so miniscule as to constitute no danger to anyone or anything.

In 1971, after prolonged testimony and negotiations, an out-of-court settlement in the amount of $700,000--divided unequally among the eighty-one members of the fifteen families involved--was agreed upon.[1]

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[1] Details of the actual partitioning of the proceeds are not available: the only accessible records of individual payments relate to minors, since they were compensated through the Public Trustee.

The settlement was effected by means of easements which permit the flow of the gaseous emissions in quantities up to, but not exceeding, those established by law. The plaintiffs are entitled to sue again if the legally permitted quantities, which are declining with time as environmental regulations become more stringent, are exceeded.[1]

At the present time, however, the Gulf[2] plant complies with the revised required recovery efficiency level of 94 per cent, primarily because of declining throughput. The Shell Waterton plant will be required to recover 98.7 per cent of all inlet sulphur and is currently installing tail gas cleanup facilities. The process, developed by Shell and known as SCOT (Shell Claus offgas treating) involves a $15,000,000 capital investment and will permit the achievement of the required efficiency when fully operational in 1976.[3] Since the new facilities process only about 70 per cent of all tail gas, higher recovery efficiencies--theoretically approaching 99.9 per cent--are possible as field productivity declines. Ambient levels are continuously monitored, and a feedback mechanism exists whereby plant operating conditions can be adjusted whenever critical levels are approached.[1] Shell has been financing an agricultural research project in the area at an additional cost of $500,000, has spent $200,000 over the last two years on soil reclamation, and conducts stringent biological assays to ensure continuously-high quality of its effluent water.[2]

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[1] The easements are on file in the Land Titles Office in Calgary.

[2] The British American Oil Company Limited is now known as Gulf Oil Canada Limited.

[3] Inasmuch as the SCOT process is a new innovation, and may therefore require some modification, Shell will only be required to recover 98 per cent during the first year of its operation.

The Nature of the Costs of Pollution

The substantial amounts that the ERCB has required Shell and other operators to invest in enhanced sulphur recovery facilities (as well as on other pollution control devices) cannot be justified by the value of the incremental sulphur nor by any other pecuniary benefit to the companies involved. The expenditures must, therefore, be primarily vindicated by countervailing external benefits, i.e., by a reduction in the costs of pollution. In this section, some of the alleged costs incurred near Pincher Creek shall be discussed through specific reference to case histories and subsequent damage claims entered by several of the families involved in the previously-mentioned litigation. However, it must be stressed at the onset of this discussion that, except where explicitly stated to the contrary, the values cited are for claims and not for settlements. Several expenditures were, in fact, disputed by defence counsel and, since a detailed independent cost analysis is beyond the scope of this thesis, the primary purpose of this section is merely to illustrate the multifarious ways in which people's lives are affected by environmental pollution.

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[1] For further detail see "Waterton Gas Processing Plant Plans 98 per cent Sulphur Recovery," Oilweek, March 19, 1973, p. 12., and "Shell Pays $15 Million at Waterton to Meet Sulphur Recovery Guidelines," Oilweek, January 21, 1974, pp. 21-24.

[2] Environmental assessment in the Waterton area is discussed in "Waterton Plant has Unique Problems and Methods to Monitor Air Pollution," Oilweek, January 21, 1974, pp. 25-26.

One of the plaintiff families--that of Mr. Gordon Wallace McRae--had lived on one of the affected parcels of land for several years prior to commencement of production at the B.A. Plant in 1957. Mr. and Mrs. McRae claimed that they and their first five children suffered from severe physical afflictions immediately thereafter, and that another child, born in 1960, was also seriously affected.

In their claim for both injuctive and monetary relief, the McRae's enumerated the physical conditions which they considered to be attributable to gas plant pollution:

> The plaintiff, Gordon Wallace McRae, is forty-three years old and has suffered from headaches and lethargy and continual sore throat and indigestion together with kidney, bladder and bowel disorders.
>
> The plaintiff, Edith Emily McRae, who is forty-three years old suffers from hives and skin rash, depression, headaches, and blackouts, and has developed a sinus condition. In addition, she has suffered from a sore chest, dry cough, sore tongue with peeling, swollen face, swollen throat, difficulty in swallowing, shortness of breath, indigestion and stomach aches, depriving her of her expectation of a normal life.

The Plaintiff, Sheila Margaret McRae is twenty years old and suffers from an allergy causing swell patches on the skin, rash, hives and itchiness, earaches and deafness. In addition, she has suffered stomach aches, loss of appetite, irritability, headaches, eye irritation, weepiness, loss of sleep and general depression, and has been deprived of the expectation of a normal life.

The Plaintiff, Kenneth Gordon McRae, is eighteen years old and has suffered from scaly skin eruptions on the face and hands, headaches, lethargy, nausea, chest pains and uneven heart beat together with eye and throat irritations, and has been deprived of the expectation of a normal life.

The Plaintiff, Donald John McRae, is seventeen years old and suffers from nosebleeds, sick stomach, loss of appetite, weepiness, general lethargy and depression and in addition, he suffers from a haemorrage condition of the eyes, depriving him of the expectation of a normal life.

The Plaintiff, Lorna Maureen McRae, is fifteen years old and suffers from rashes, hives, headaches, stomach aches, dry cough, diahorrea and a bladder condition. In addition, she has suffered eye irritation and blisters on the eyeballs under the eyelids, weepiness and tears which interferes with her vision and deprives her of the expectation of a normal life.

The Plaintiff, Malcolm Wallace McRae, is thirteen years old and suffers from diahorrea, weepiness, an eye condition together with skin rash and allergy. In addition, he suffers from nosebleeds, dry cough, headaches, nausea and periodic coma-like sleep which has deprived him of the expectation of a normal life.

The Plaintiff, Barbara Ann McRae is nine years old and suffers from digestive upset, diahorrea and continuous crying throughout the day with vomitting. She suffers from puffy swellings under her eyes causing irritation and resulting lack of sleep. Due to the extreme diahorrea she has become dehydrated with the result that this Plaintiff may become retarded physically and mentally from lack

> of food. This Plaintiff is underweight and height for her age and has had a continual problem with retaining food causing lethargy and depriving her of the expectation of a normal life.[1]
>
> Furthermore:
>
> On account of the said complaints, all of the infant Plaintiffs have all been precluded from a normal childhood and have had their recreational activities curtailed and have suffered in their schooling advancements. Each of the infant Plaintiffs claim the sum of $5,000.00 on account of general damages for personal injuries and damage to health.[2]

Mrs. McRae stated at the Public Hearing that the symptoms were alleviated when plant upsets were remedied, when gas well testing ceased, or when the family left the area. She also felt that the family had been sensitized to the fumes, and that upon re-entering the polluted area, the symptoms reappeared with less exposure than had been required to provoke them initially.[3] However, the third child had worked at age 19 at the Shell plant without a recurrence of eye trouble, hives, or nosebleeds. Mrs. McRae attributed this fact to the downwind location of their farm, which could therefore receive a different level and type of pollution than that occuring around the plant.[1]

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[1] Gordon Wallace McRae and Family vs. Shell Canada Limited and The British American Oil Company Limited, Southern Alberta Supreme Court, File 83085, (1967), "Ammended Statement of Claim," pp. 6-9; settled out of court, 1971. This statement cites the ages of plaintiffs in 1970 when the revised claim was entered. A more graphic description of the afflictions may be found in Mrs. McRae's testimony at the Public Hearings. See Environment Conservation Authority, *Environmental Effects of the Operation of Sulphur Extraction Gas Plants: Proceedings of the Public Hearings*, I (Edmonton: 1972), pp. 322-324.

[2] *McRae vs. Shell and B.A.*, "Ammended Statement of Claim," p. 9.

[3] Environment Conservation Authority, *Public Hearings*, I, p. 324.

Domestic animals were also affected:

> On account of the spread of noxious and offensive gases over the Plaintiff's land, the Plaintiff's swine operations have been affected in that the entire herd has suffered from sore eyes, lack of appetite and malaise with the result that there has been a loss of thriftiness in the Plaintiff's swine operations and a reduction in the increase in the size of the herd which condition will continue. On account of increased mortality in the litters of pigs due to noxious and offensive gases, the Plaintiff ceased all swine operations in 1964 and suffers a permanent loss of income on account of this.
>
> On account of the spread of noxious and offensive gases over the Plaintiff's land, the Plaintiff's cattle operations have been affected in that the entire herd has suffered from sore eyes, lack of appetite and malaise with the result that there has been a loss of thriftiness in the Plaintiff's cattle operations and a reduction in the increase in the size of the herd which condition will continue.[2]

Accelerated corrosion of fence wire, machinery, and tools necessitated their replacement at an earlier time than normal and it was further claimed that:

> The spread of noxious and offensive gases throughout the area has received wide publicity and notoriety and the Plaintiff, Gordon Wallace McRae, has suffered damage due to the decrease in value of "the said lands.[3]

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[1] Ibid. In connection with the same statement, Mrs. McRae noted that the children were now (1972) of above average height and had good athletic ability and average scholastic ability. However, two children had a tendency to develop lung ailments, and one was allergic to penicillin; the rest were allergy free.

[2] McRae vs. Shell and B.A., "Ammended Statement of Claim" p. 6.

[3] Ibid., p. 5.

A claim of $19,000 was entered for decreases in the value of the land.

During the early and mid 1960's, the plaintiffs were forced to leave their property and seek temporary accomodation on several occasions. In May 1967, they moved to a farm in the Beaver Mines Area west of Pincher Creek, but continued operations at their old location, thereby incurring additional travel expenses.

Specific damages of $4288.37 were claimed for the costs of temporary evacuations, moving the farmhouse to the new property, mortgage interest and legal fees relating to the land purchase at Beaver Mines, and commuting expenses incurred prior to the initiation of legal action. Medical expenses amounted to $122.25 and wages for special help at the old farm totalled $882.80.

Mr. McRae also claimed $25,000 in general damages, costs of the action, and $20,000 for the expense of commuting (26 miles round trip) indefinitely. Mrs. McRae claimed general damages of $10,000 plus costs, and, as noted earlier, each of the six infants claimed $5000 (plus costs).[1]

Each of the five youngest children received $1000 through the Public Trustee, while the oldest child reached the age of majority prior to the out of court settlement and was presumably compensated privately.

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[1] _Ibid._, p. 5-10.

Testimony by other plaintiffs corroborated the allegations of Mr. and Mrs. McRae. For example, Mr. John Presley Marcellus stated that his family had also been forced to temporarily vacate their property "on account of the noxious and offensive gases."[1] Indeed, physical symptoms similar, but not identical to, those encountered by the McRae's, were experienced by Mr. and Mrs. Marcellus and their four children.[2]

In October 1968, the plaintiff moved permanently to Pincher Creek and therefore had to commute thirty-six miles per day. During Examination for Discovery, Marcellus stated that this arrangement was a source of inconvenience to his wife, that certain evening jobs could not be performed as well as before, and that he no longer felt he was a member of the community. He asserted that he was losing an estimated five calves per year due to pollution, that cattle were forty pounds below normal, and that, due to excessive corrosion, some of his equipment was worth 25 per cent less than regular market value.

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[1] John Presley Marcellus and Family vs. Shell Canada Limited and The British American Oil Company Limited, Southern Alberta Supreme Court, File 83085, (1967), "Ammended Statement of Claim," p. 3; settled out of court, 1971.

[2] Ibid., p. 7-8. It must be emphasized that there also exists considerable variation in the nature and extent of symptoms within families whose members are equally exposed. The fact that some individuals are more susceptible than others presents a dilemma for policy makers--given that resources are scarce and have alternate uses, should ambient standards be set sufficiently low to protect fifty, ninety, or one hundred per cent of the population?

Marcellus further stated that he would have to alter his winter feeding operations to facilitate efficient production while living in Pincher Creek, and would thereby incur additional expenditures of approximately $10,075--primarily for new cattle sheds, corrals, a hay shelter, and special winter vehicles.[1]

A survey of other damage claims revealed several other evacuations, details of which shall not be presented. The "typical" statement claimed $25,000, $10,000, and $5000 (plus costs) in general damages for husband, wife, and each infant, respectively. Alleged property damages were approximately $30 per acre, although some claims went as high as $75 per acre. Infant plaintiffs generally received from $1000 to $2000 although several very young children received only $500.

At no time before, during, or after the litigation did Shell or B.A. make any admission of fault or liability. They did, however, negotiate a $700,000 out of court settlement for the right to discharge gaseous effluents up to the current legal limit, and a casual observer might well construe the nature of the agreement as a tacit admission of some degree of guilt.

Discussion of the Settlement

Despite the uproar about environmental pollution in various parts of the world, there has nevertheless been a paucity of successful damage suits. As noted previously, the burden of proof, the nebulous nature of many of the alleged damages, and the disparate powers of the adversaries all weigh heavily on the plaintiff.[1] The mere fact that a financial settlement was, in fact, reached at Pincher Creek is a tribute to the perserverance and tenacity of the plaintiffs and their legal representatives.[2] Furthermore, Shell's more dignified attitude with respect to environmental preservation may hopefully be construed as a sign that at least a few large corporations are becoming cognizant of their social responsibilities.

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[1] *Ibid.*, p. 60. The proposed expenses were included to substantiate the plaintiff's allegations of injury, but were not claimed specifically.

Nevertheless, the question persists: Does the $700,000 out of court settlement realistically reflect the total costs of pollution from 1957 to 1970?[3] The issue assumes particular importance in view of Shell's scheduled

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[1] On the other hand, consider the adverse publicity generated for two large corporations, both of which have international retailing networks.

[2] The success of the plaintiffs is also highly attributable to the fact that the allegedly-noxious gases emanated from only two readily-identifiable and stationary facilities. The antithetic scenario would be a lawsuit alleging emphysema from pollution in downtown Los Angeles.

[3] There are approximately twenty-five families on the fringe of the affected area who did not participate in the lawsuit, but who may have received minor compensation from the companies subsequent to the out of court settlement in 1971. The companies have also arranged several land swaps to residents affected by sulphur dust from the stockpiles, but this consideration is not relevant to the argument regarding enhanced sulphur recovery which follows.

$15,000,000 investment in tail gas cleanup equipment. Incremental sulphur recovery from the SCOT process unit will only be 84.1 LTD at maximum throughput, and the incremental revenue at early-1973 prices represented only about one-sixth of additional operating costs.[1]

If, in fact, the additional costs of meeting the guidelines were incurred solely to partially abate Shell's share of $700,000 in damages--or, for that matter, three times that amount--spread over at least eight years, the MCC=MCP criterion would appear to have been violated.[2] Indeed, the entire thirty million dollar estimated expenditure on enhanced sulphur recovery facilities throughout the province may be disputed in an analogous manner.

Does MCC=MCP?

The Kaybob South Beaverhill Lake plant provides a further, less complicated, example of the apparent discrepancy between MCC and MCP. Under the new guidelines, the operator--

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[1] "Waterton Gas Processing Plant Plans 98% Recovery," Oilweek, March 19, 1973, p. 12. Other tail gas processes offering the same efficiency are available for about half this price, and no satisfactory reason could be obtained for the utilization of the SCOT process.

[2] Strictly speaking, the present value of the additional costs of control over the expected remaining life span of the plant should be compared with the present value of the marginal benefits of control--which may increase with time. Since Shell did not apply for a permanent exemption, detailed financial figures are not available. If, however, the analysis is confined to the existence of the inequality, as opposed to its magnitude, the problem of exact quantification is obviated by the substantial initial outlay on abatement equipment.

Hudson's Bay Oil and Gas Company Limited (HBOG)--will be required to install tail gas cleanup equipment to increase recovery from 96 per cent to 98 per cent. An initial investment of $3,470,000 will be required and incremental operating expenditures are estimated at $350,000 per annum.[1] Maximum incremental sulphur recovery will be only 15,390 LT/Y, which amounts to a plant netback of less than $50,000 at 1972 prices, and less than $200,000 at the ERCB's long run forecast price of $12.00/LT.[2] Furthermore, sweet gas breakthrough is anticipated in 1976, and will lower the total sulphur intake.[3]

Despite the fact that approximately one-third of the province's total SO_2 emissions from sour gas processing plants emanate from the general area in which the HBOG plant is located,[4] the only apparent damage was temporary vegetative stress.[5] Nevertheless, the operator was refused an exemption, and was required to install tail gas equipment as previously directed. Again, the discrepancy between MCC and MCP is clear, and, given the paucity of documented, quantifiable damages in many parts of the province, the entire concept of "enhanced sulphur recovery" must be further investigated.

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[1] HBOG, Kaybob South Beaverhill Lake Gas Processing Plants I and II: Application for Exemption from Sulphur Recovery Guidelines, submission to the ERCB, (Calgary: May 30, 1972), p. 2. The ERCB estimated a slightly higher initial investment, and confirmed the general veracity of the operator's statements.

[2] Ibid., p. 4

[3] Ibid., p. 1.

[4] The Chevron Kaybob III and Texas Gulf-Amoco Windfall Plants--both of which are in category I--are nearby.

[5] "Pollution Effects Target in New Study," Financial Post, November 25, 1972, p. o-2.

There would appear to be three possible explanations for the *prima facie* evidence that MCC $>$ MCP:

1. The government has, in fact, overestimated the costs of pollution, and has, as the industry steadfastly maintains, therefore requested an unjustifiable expenditure on pollution abatement.
2. Monetary re-imbursements account for only a small fraction of the "true" cost of pollution.
3. The welfare-maximizing dictum is not a realistic description of the *modus operandi* of public decision makers.

Each of the various interest groups involved with pollution from sour gas processing undoubtedly has its own adamant preconceived notion as to which of the above explanations (or combinations thereof) most aptly reconciles the apparent divergence. Hopefully, at least a small degree of empathy may be introduced into a somwhat polarized situation by the following, more neutral, discussion of the three explanations.

The industry position was well summarized in its submission to the Environment Conservation Authority in conjunction with the 1972 Public Hearings:

> It seems to us then, that before increased gas-plant efficiencies are legislated, consideration must be given to the receiving environment. If it can be established that gas plants, on an individual basis, have caused no environmental degradation, there is no logic to requiring increased sulphur recovery efficiencies.[1]

The primary contention of the CPA submission was that ambient standards, rather than recovery standards, should be the dominant criterion. The report cites the results of many scientific studies which, it claims, attest to the adequacy of existing ambient standards. The CPA further claimed that the industry was attaining the stipulated ambient levels except under extremely unusual operating conditions. Why, then, should the industry be requested--almost required--to expend from thirty to forty million dollars on enhanced sulphur recovery, when it could use the natural assimilative capacity of the atmosphere for free?[2] If one assumes for the moment that policy makers are indeed guided by the rules of welfare maximization, the answer to this incessant industry query must be found in the "hidden costs of pollution" explanation, or not at all.

In actual fact, there are at least four theoretically--sound reasons for expecting that not all pollution costs will be resolved through negotiation.

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[1] Canadian Petroleum Association, The Environmental Effects of the Operation of Sulphur Extraction Gas Plants in Alberta, Submission to the Environment Conservation Authority, (Calgary: 1972).

[2] The actual cost to the industry will be somewhat lower due to the capital cost allowance. However, the burden is not readily shifted to natural gas consumers, since most of the operators have signed non-negotiable sales gas contracts.

First, neither the long term effects of all pollutants nor their synergistic effects are known with certainty,[1] and disutility is associated with any form of uncertainty. This disutility--perhaps accurately perceived only by environmental scientists--and the subsequent "insurance premium," for which no private market exists,[2] is one of the hidden costs of pollution. The insurance can only be "bought" through the establishment of standards which hopefully provide a margin of safety.[3] We can gamble with our dollars--by spending too much on pollution abatement--or, we can gamble with our health and our environment--by spending too little.

Second, there exists considerable inertia towards litigation. Some individuals are uncertain as to how to proceed, and others (particularly those who are especially sensitive to a contaminant, and who observe that others around them are seemingly unaffected), may decide to tolerate the nuisance rather than give the impression of being a troublemaker, a money grubber, or a neurotic.[1] Furthermore, the frequently-obscure nature of the damages and the associated difficulty of documentation; the arduousness of discrediting other possible sources of the external effects;[2] and the psychological, opportunity, and out-of-pocket costs of claiming damages, all act as a barrier to the resolution of pollution costs. Going to court, or even documenting damage claims, imposes a significant psychological burden on many people, since it displaces them from their normal workaday routine into an unfamiliar and somewhat hostile atmosphere. Lawyers and landmen may enjoy--even thrive on--the jousting, but can the same be said about the average Alberta farmer? The totality of factors which comprise the "burden of proof"[3] may weigh too heavily on the plaintiff: lack of action, therefore, does not necessarily imply zero damages.[1]

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[1] For a discussion of current Alberta research, see M. Nyborg, and McKinnon, Allen and Associates, Ltd., "Atmosphere Sulphur Dioxide: Effects on the pH and Sulphur Content of Rain and Snow; and Addition of Sulphur to Surface Waters, Soil and Crops," in D. Hocking and D. Reiter, eds., Proceedings of a Workshop on Sulphur Gas Research in Alberta, (Edmonton: Northern Forest Research Centre, 1973), Information Report NOR-X-72, pp. 79-97.

[2] A private insurance market cannot help protect future generations, and will, in any event, be subject to the free-rider problem.

[3] This argument would appear to be somewhat analogous to the concept of a "safe minimum standard" developed in S.V. Ciriacy-Wantrup, Resource Conservation: Economics and Policies, (Berkeley: University of California Division of Agricultural Sciences, 1968), Chapter 18.

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[1] On the other hand, there apparently exists a very small subset of the population who attribute almost every personal and agricultural misfortune entirely to gas plant pollution.

[2] This problem is exacerbated by the existence of overlapping sources of pollution. Vociferous complaints registered at certain Central Alberta gas plants have, on occasion, been precipitated by upset conditions at installations many miles away.

[3] The Waterton gas plant now checks effluent water quality continuously by means of a biological assay fish survey. The burden of proof has, in this case, therefore been shifted towards the industry. See "Waterton Plant," Oilweek, Jan. 21, 1974, p. 26.

Third, the willingness of concerned citizens to forsake other activities to attend public hearings and, in some cases, to even prepare briefs, present evidence, or engage in other forms of political activity is ipso facto evidence that they perceive the existence of pollution costs in some forms.[2] Furthermore, it is important to note that the political activities are undertaken despite the free-rider aspect of pollution abatement: attendance at a meeting does not automatically confer a benefit in the form of reduced pollution, and non-attendance does not exclude anyone from benefits which may nevertheless ensue.

An old political adage states that one letter from a constituent is equivalent to one hundred votes. Similarly, and abstracting from the formidability of quantification and the emergence of "game strategies" if the mode of calculus became generally known, should not a dollar value be imputed to attendance at public hearings and even to complaint calls?[3]

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[1] The above arguments both support the hypothesis that damage settlements (with or without explicit admissions of guilt) understate the true cost of pollution. Acceptance of this hypothesis does not, however, necessarily imply that MCC = MCP.

[2] It is conceded that the hearings may have some compensating entertainment value.

[3] A leading civil servant has pointed out a further complication. The level of awareness of possible detrimental effects varies substantially in society with income, occupational status, and education. Thus it is not inconceivable that a small group of environmentally-aware citizens residing in an area where only small damages are occurring may exert more political pressure than less-informed citizens facing a much more serious problem.

A final reason for expending more on pollution abatement than can be justified on the basis of documented, quantifiable damages is that certain costs are of an aesthetic, rather than a tangible, nature. Farm families, accustomed for generations to fresh air, were suddenly subjected to a veritable witches' brew of noxious odors. Unless the unpleasant emissions could be specifically associated with some tangible damage--and even then the case was tenuous--the costs were ignored. Nevertheless, they constitued a very real loss of utility which could only be regained by some form of political activity.[1]

The third hypothesis which sought to explain the apparent divergence between marginal costs and benefits of pollution abatement was that public policy makers simply do not operate within the cost-benefit framework. To be sure, there are seemingly insurmountable problems associated with a literal interpretation and implementation of the technique, a few of which have already been mentioned.[1] But this apology evades the current question: What is the objective function of government?[2]

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[1] Although aesthetic considerations are extremely important in any comprehensive study of all the causes and effects of gas plant pollution, they are less relevant in the context of enhanced sulphur recovery than are the three previously-cited arguments. Theoretically, the short run ambient standards--which are below the odor and taste thresholds of 3 ppm and 0.3 ppm respectively--are almost always met through dispersal techniques. Nevertheless, there exists a finite possibility that the severity of an episodic event--caused, perhaps, by a plant upset during adverse meteorological conditions--may be diminished if additional sulphur is recovered from an installation that apparently has adequate stack dispersal to satisfy ambient standards under regular conditions.

Breton's theory that governments maximize the probability of re-election has already been mentioned in another context.[3] If this hypothesis is accepted, (and the massive expenditures on political campaigns and the resultant plethora of election-time promises provides *prima facie* evidence to its general validity), one must then ask: To what extent is MLA (or whatever) maximization consistent with welfare maximization?

Although many citizens would hasten at this juncture to point out the inordinate political power of the multinational petroleum corporations--and could undoubtedly provide many salient examples thereof--the issue is much more complicated. First, it is an unassailable historical fact that the Department of the Environment was established and the associated Clean Air, *etc.*, legislation introduced in the dying days of the Social Credit administration.[4] Furthermore, the enhanced sulphur recovery guidelines were circulated less than three months after the election of the Progressive Conservatives in August 1971, and the province-wide public hearings were conducted before another year had passed. Can all these activities be dismissed as mere "sops" to environmentalists, whilst permitting the corporations to reign supreme? Or have the environmental pressure groups--including civil servants--genuinely succeeded in demonstrating the existence of hidden external costs to the politicians? Recalling that pollution abatement has public good characteristics[1] and that preferences for public goods are often expressed through the political process, a previously-cited statement of Breton's is well worth repeating:

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[1] *Supra*, p. 70.

[2] Furthermore, are the objectives of politicians and civil servants the same?

[3] *Supra*, pp. 26-27.

[4] It is also interesting to note that the out of court settlement at Pincher Creek was finalized at almost exactly the same time as the Department of the Environment was established.

> It should be observed that even though individuals are in disequilibrium with respect to the supply of public and private goods considered in isolation of the political process, they are in full equilibrium once we take account of their political power which, of course, is always given in terms of the political power of others in society.[2]

The quotation is relevant in the current context for two reasons. First, if its conclusion is accepted and combined with the environmental improvements legislated during and subsequent to 1971, one may reasonably conclude that some environmental pressure groups are making (albeit belatedly from the standpoint of some central and southern Alberta residents) their presence felt at the political level.[1] Second, the "disequilibrium" mentioned by Breton refers to the fact that preferences for public goods are not accurately revealed: Is there a tendency to overstate or understate preferences for pollution abatement in the sour gas processing industry?

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[1] The fact that the petroleum corporations are supplying the abatement facilities is irrelevant: the basic public good characteristics of indivisibility and non-excludability are still present.

[2] A. Breton, "Public Goods," p. 465.

Samuelson's early literature suggests that preferences are understated due to freeloader effects. However, this conclusion rests on the assumption of benefit taxation and is therefore inapplicable in the current pragmatic context.[2] If environmentalists perceive pollution abatement as a "free" good--in the loose sense that the costs thereof are borne entirely and forever by corporations--they may well overstate their preferences. A study should therefore be conducted to determine how the average Alberta citizen qua environmentalist allocates the total costs of pollution abatement in various industries between industry, taxpayers, and consumers in Alberta and elsewhere.

In summary, then, the purpose of this section has been to argue that the recent massive expenditure on pollution control equipment in the sour gas processing industry cannot be justified by documented externalities; to suggest, however, that there exist strong theoretical arguments attesting to the understatement of the true costs of pollution; and to discuss the ramifications of vote-maximizing behavior in the political arena. Due to the paucity of useful numerical data, no inexorable conclusions can be proffered as to whether too much or too little is being expended on pollution control. Nevertheless, it remains abundantly clear that the presence of hidden pollution costs necessitates some degree of paternalistically-stipulated "over expenditure" on pollution abatement. The manner in which the ERCB policy with respect to enhanced sulphur recovery tacitly (but hopefully deliberately) takes these costs into account shall now be discussed.

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[1] On the other hand, it might be plausibly argued that the government's policy of occasionally granting an exemption from pollution regulations because of profit considerations in the private sector constitutes a political dance for a different fiddler.

[2] The freeloader effect remains important in that it may inhibit one's tendency to join an anti-pollution group or to engage in other types of environmental activity which offer non-excludable benefits.

Analysis of Exemption Decisions

The question as to whether or not current environmental regulations give implicit recognition to the existence of externalities may be approached through an analysis of several of the regulatory bodies' decisions regarding applications for exemption from the enhanced sulphur recovery guidelines.

Firms applying for exemptions were required to submit a detailed economic analysis of their operations to the ERCB, together with technical information pertaining to the nature and effectiveness of existing anti-pollution equipment.

If the Board received submissions of intervention, the company was required to defend its application at a public hearing. The ERCB then prepared a decision document based on all relevant information and submitted it to the Department of the Environment for final approval.

Harmattan-Leduc Decision

On June 21, 1972, the Board handed down its first decision, on the Harmattan Leduc Gas Processing Plant.[1] The plant is operated by Canadian Superior Oil Ltd., and processes natural gas containing 53 per cent H_2S from the Leduc formation. Another facility, known as the Harmattan Area Plant, is located on the same site and, although also operated by Canadian Superior, has a different consortium of owners. This plant was constructed for the purpose of cycling gas from the Elkton Pool back into the same formation to enhance the recovery of liquid hydrocarbons. Only about 4 per cent of the gas, which is slightly sour--about 0.5 per cent H_2S--was transmitted to the sulphur recovery facilities at the Harmattan Leduc Plant. Therefore, the Harmattan Area Plant was not directly affected by the sulphur recovery guidelines. It was, however, naturally subject to other environmental regulations, and had, in fact, been the source of many complaints in the past.

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[1] ERCB, *Exemption from Sulphur Recovery Guidelines: Harmattan Leduc Gas Processing Plant*, Decision 72-8, (Calgary: June 21, 1972.)

Prior to the publishing of the new guidelines, the Harmattan Leduc Plant was required to recover at least 95 per cent of its sulphur and was not permitted to discharge more than 25.3 LT/D of that element to the atmosphere. The operation was losing about $90,000 per year due to depressed sulphur prices. However, inasmuch as the operator had a commitment to the Canadian Pacific Railway to ship 1.25 million tons of sulphur over a specially-built seventeen mile rail system from the plant to Didsbury, it was continuing operations in the hope that sulphur prices would increase in the future. Closing of the plant at that time would have necessitated a payment of more than half a million dollars to the C.P.R. for sulphur not shipped.

The new efficiency requirement was deemed to be 96 per cent, and although the plant had operated at 95.5 per cent during 1971, Canadian Superior did not feel that the existing equipment could be sufficiently upgraded without the installation of tail gas cleanup facilities. The most suitable process would have required an expenditure of from $1,200,000 to $2,000,000, but the incremental sulphur recovery would have been less than five tons per day, and not even worth $15,000 at 1972 prices. The operator stated that inasmuch as the Plant was already unprofitable, the imposition of a further uneconomical expenditure would precipitate a serious discussion with its partners regarding plant closure.

The hearing of the application for an exemption commenced at ERCB offices in Calgary on March 29th, 1972 and after adjournment was subsequently continued in Olds on April 26, 1972. Fifty-four residents in the general area of the plant wrote or signed interventions and an intervention was also received from the County in which the plant is located. The Board noted:

> All the interveners stated their opposition to the application of Canadian Superior for exemption from the sulphur recovery guidelines. While it appeared that certain of the interveners were under the impression that the application was for an increase in emissions, almost all stated that the plant should be made to reduce emissions.
>
> Most of the submissions were in the form of complaints of pollution in the area. Incidents of sick cattle, dead vegetation, corroded machinery and human discomfort and distress were reported and in some cases were attributed to pollution from the Harmattan Leduc Plant.[1]

The complaints were well articulated, and many were documented with not-so-shining examples of corrosion. Notwithstanding the severity of the allegations, many of the claims were similar to those already mentioned in other contexts, and shall therefore not be elaborated upon. However, a special feature of the hearing was a testimony by Dr. H. Sutmoller, a local veterinarian. Dr. Sutmoller was concerned about a possible relationship between excessive sulphur in the soil and a form of muscular dystrophy in animals caused by selenium deficiency. The Veterinarian later submitted another brief on this topic at Red Deer in October 1972 in conjunction with the Province-wide Public Hearings. At that time, he discussed the disease--the frequency of occurrence of which is increasing in Alberta:

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[1] *Ibid.*, p. 160.

> Selenium deficiency in animals is characterized by poor skeletal muscle formation. Grossly in some cases the muscle has a pale appearance, hence the name "White muscle disease"; however this is only one manifestation of the disease and since most of the changes are microscopic and can not observed grossly, it is more proper to call this disease "Nutritional Muscular Dystrophy" (NMD). Clinically this condition in calves up to 3-4 months of age is characterized by stiffness, muscular weakness, and rapid death if the heart muscle is severly affected. Stillbirth of calves is common if the dams are on a low selenium diet. The clinical effects of selenium deficiency are so widespread that it is common usage to refer to such conditions as "selenium responsive," in other words treatment with selenium may produce dramatic results. Examples of such conditions are: chronic diarrhea, unthriftiness, abortions, infertility, degenerative heart conditions, hepatosis (liver degeneration). These conditions are difficult to recognize but can be of great economic importance because of their insidious nature.[1]

A possible cause may have been the inhibitory effect of sulphur on selenium intake:

> Both elements are chemically closely related and are essential in cell metabolism because of their involvement in synthesis and activation of cell enzyme systems. S substitutes easily for Se in biological systems. In the presence of abundant S the cell may take up S in preference to Selenium. If the problem is aggravated by low Se levels in the soil to start with, it is very likely that very little Se is absorbed in the plant. This inhibitory effect takes place as the plant extracts

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[1] Dr. H. Sutmoller, "Observations on the Effect of Sulphur on the Selenium Level in Soils," Alberta, Environment Conservation Authority, Proceedings of the Public Hearings, I, p. 426. The author also provides an extensive bibliography of similar research findings in other parts of the world.

nutrients from the soil and in a lesser degree when the animal digests plants low in Se and relatively high in S.[1]

Although the ERCB was of the opinion that many of the pollution problems in the subject area stemmed from environmentally-inefficient field operations and from other processing facilities--notably the Harmattan Area Plant--rather than from SO_2 emissions, Dr. Sutmoller's testimony was nevertheless extremely important for several other reasons. First, it served as a ready repudiation to statements, occasionally made by a small group of sulphur industry representatives, that any form and quantity of sulphur eventually deposited in the soil as a result of SO_2 emissions was automatically beneficial. (Ignoring welfare functions of man and beast alike, these individuals decry the "inefficiency" of recovering elemental sulphur at a gas plant, shipping it to a fertilizer plant, and then transporting the finished product back to the very (sulphur-deficient) area in which the gas plant is located). Second, and more important, Dr. Sutmoller's paper underlines the necessity of limiting total SO_2 emissions: this consideration is especially relevant in Central Alberta due to the prevalance of overlapping sources.

After considering plant economics, the relatively small reduction in sulphur emissions that would result from the installation of tail gas cleanup equipment, and the nature and extent of the alleged social costs, the ERCB granted an exemption from the upgraded sulphur recovery guidelines, but ordered the operator to take immediate remedial action to correct other important causes of pollution at the Harmattan Leduc and Harmattan Area Plants. These included, among other things, the installation of a smokeless flare; restrictions on sour gas and fluid flaring at well sites, battery sites, and burn pits; and the requirement that sweet gas be added to acid gas in sufficient quantities to ensure complete combustion when flaring. The ERCB also called upon the operator to install extra SO_2 monitoring devices and requested the Department of the Environment to do likewise.

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[1] Ibid., p. 427.

The decision is also particularly noteworthy for its elucidation of the initial ERCB philosophy as to exactly what constituted "economic sulphur recovery."

> On the subject of an overall policy respecting applications for exemption from the sulphur recovery guidelines, the Board believes such applications should be considered on the basis of both economic conservation and the impact on the environment of the emission to the atmosphere of sulphur not recovered. Having regard for the objective of reducing total emissions to the atmosphere, the Board's assessment of the economics of increased sulphur recovery will not be on an incremental basis but rather will normally deal with the total sulphur recovery operation. In cases where, because of the plant location relative to communities or farmsteads or because several plants are located near each other, the environmental aspects of a situation are more important, the Board may look at the overall economics

> of an entire operation including costs and revenue related to the recovery and sale of residue gas and liquids prior to ruling of an application.[1] (Italics mine.)

Although it is immediately apparent that the aforesaid method of evaluation is not consistent with profit maximization, it is equally clear that profit maximization is inconsistent with welfare maximization if external costs are inflicted upon innocent third parties. The stated policy would therefore appear to be an attempt to internalize some of the alleged negative externalities by forcing the gas plant operators to use profits from existing sulphur and natural gas sales at the same location to subsidize enhanced recovery. Unfortunately for residents in close proximity to the Harmattan Leduc Plant, a subsidy-like arrangement was not feasible in 1972. The extremely low price of sulphur, coupled with a non-negotiable sales gas contract for $.1382 per MCF served to render the entire operation uneconomic and the added financial burden of tail gas cleanup might have precipitated closure of the plant. The ERCB did, however, reserve the right to reconsider its decision to grant an exemption if statutory ambient levels were violated or if the market for sulphur improved significantly. Inasmuch as the plant price for new sulphur contracts currently (mid-1974) exceeds $20.00 per long ton--well in excess of the 1972 price of approximately $7.00 or Canadian Superior's long run projection of $12.00 to $15.00, a re-assessment of the Harmattan Leduc Plant's entire financial situation should be initiated by the ERCB if prices remain relatively high.

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[1] ERCB, Harmattan Exemption, p. 162.

Crossfield (Balzac) Decision

The ERCB philosophy with respect to the "incremental" vs "total" approaches was clarified, though slightly modified, in a decision handed down on January 25, 1973 regarding the exemption request of the Crossfield Gas Processing Plant.[1] The operator, Petrogas Processing Ltd., requested that the recovery efficiency of its plant be set at 97 per cent rather than 98 per cent for their maximum inlet sulphur rate of 1700 LT/D. The operator claimed that, due to the necessity of installing a tail gas cleanup unit as well as higher operating costs, the incremental sulphur would cost $96/LT to produce. Although granting the request would necessitate an emission of 102 LT/D of SO_2 rather than 68LT/D, the operator stated that minimal damage had occured--even at only 96 per cent recovery. The ERCB concurred:

> The Board accepts the studies submitted by Petrogas regarding monitored air quality, atmospheric corrosion rates and crop and soil conditions in the vicinity of the plant as a satisfactory indication that to date, local environment damage due to emissions from the plant incinerator stack has not occurred. Monitoring has indicated commendable operations with respect to

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[1] ERCB, Exemption from Sulphur Recovery Guidelines: Crossfield Gas Processing Plant, Decision 73-2, (Calgary: 1973.)

> Provincial Air Quality Standards, and the lack of recent complaints indicates that the plant operation has been satisfactory with respect to protection of the local environment.[1]

Nevertheless:

> . . . the Board intends the minimum sulphur recovery efficiency guidelines to be an overall control of plant operations beyond, and essentially independent of, local environmental protection. . . . The Board believes that, even though by present ground level standards the environmental aspects of a plant operation might be satisfactory, maximum practical sulphur recovery should be achieved both in the interests of conservation of a natural resource and to minimize overall sulphur dioxide emissions and the potential for adverse environmental effects on a broad scale. The sulphur recovery guidelines are designed to provide for a sulphur recovery level that is as high as is practical having regard for both economics and sulphur recovery technology.[2]

The ERCB then stated the economic policy that would be used in assessing this, and further requests:

> Provided the local environmental aspects of a plant operation are satisfactory and considering that for normal cases the industry is treating sulphur as a by-product, the Board believes that, in general, the sulphur recovery should be at the level which would give a discounted rate of return in the range of seven to ten per cent on the total undepreciated investment attributed to the total sulphur recovery facilities evaluated as at January 1, 1975. Under present conditions any higher levels of profitability of sour gas processing must be maintained through prices of recovered hydrocarbons. In special cases, where income from sulphur sales is a significant portion of overall plant income and sulphur cannot be considered a by-product, the Board, before ruling on an application, may consider the overall economics of an entire operation including costs and revenue related to the recovery and sales of residue gas and natural gas liquids. In deciding individual cases

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[1] *Ibid*., p. 46. No interventions were filed, despite the proximity of the plant to Calgary. (The operator is assisting local farmers in reclaiming soil acidified by sulphur dust from the stockpile.)

[2] *Ibid*.

> within the rate of return range of seven to ten per cent before income tax the Board would have regard for the nature of the development in the general plant area and other general matters.[1] (Italics mine.)

The upshot of their calculations was that the "incremental" loss was transformed into a rate of return on total sulphur investment of at least 13 per cent and the application for exemption was therefore denied.[2]

Although one may well dispute the arbitrary use of a 7-10 per cent rate of return--which presumably reflects the riskless rate--and perhaps the entire concept of treating sulphur as a by-product,[3] this approach nevertheless appears to be a politically expedient method of reducing the long term effects of SO_2 emissions.

The basic deficiency of this arrangement from an economist's standpoint is its attempt to satisfy two conflicting objectives: first, the reduction of total sulphur emissions; and second, the attainment of a seven-to-ten per cent rate of return on sulphur recovery to a subset of the operators who were not causing noticeable environmental damage. The rate of return to an individual operator is irrelevant from an environmental standpoint: however, until social scientists succeed in quantifying more of the true costs of pollution, this mixed-objective stance may well prevail.

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[1] _Ibid_.

[2] _Ibid_., p. 47. The calculations were conducted using both "high" and "low" estimates of future operating costs and royalties. They assume a sulphur price of $7.50/LT in 1975, increasing to $12.00/LT by 1979, and sales at 50 per cent to 60 per cent of production.

[3] It is difficult to conceive of sulphur and sales gas as being anything but _joint_ products: indeed, the petroleum corporations almost invariably utilize this approach in their capital budgeting. Perhaps the term "by-product" came in vogue due to the relatively-small amount of sulphur produced at some plants and the fire-sale prices which prevailed earlier in this decade.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Environmental pollution is of particular interest to economists because the externality and public good problems which it poses are not automatically corrected by the market system. This thesis has attempted to discuss the theoretical concepts of environmental economic analysis in the context of the sour gas processing industry in Alberta, and to thereby demonstrate the necessity of appropriate regulatory action therein. Although two of the models presented in the theoretical chapter demonstrated that a Pareto-optimal state could, in fact, be attained through private bargaining, the stringent and somewhat unrealistic assumptions upon which such results were contingent precludes the applicability of Coase-type solutions in most pragmatic situations--including the Alberta problem under consideration. The arduousness of organizing for collective behavior in the face of psychological inertia and non-excludable benefits; the disparate economic powers of the antagonists; the saddling with the burden of proof despite the lack of readily-obtainable information; and, the difficulty of precisely identifying both the source of pollution and its actual effects, all act as powerful deterrents to private bargaining. Externalities can, in fact, only be effectively internalized by legislative decree: no sociologically-enlightened citizen would today advocate Coase-type solutions as a panacea for environmental disruption.

Given, therefore, that pollution is a collective issue that must be solved, by and large, by collective action, the economic problem reduces to the determination of the optimal level of pollution abatement.

The theoretical usefulness of the MCC=MCP principle in this regard is undermined by the paucity of reliable data concerning the true economic costs of pollution, and it was therefore argued that the regulations should provide a margin of safety against unforeseen detrimental effects. The practice of insuring against potential risks--even against being late for work--pervades our everyday lives, and it would therefore appear irrational for people not to demand insurance against the long term effects of pollution, particularly when many of the benefits from Alberta natural gas production accrue to individuals outside the province, and when, in fact, much of the abatement costs will similarly be borne by outsiders. The regulatory bodies have apparently attempted to provide a margin of safety through the enhanced sulphur recovery guidelines, but have retreated somewhat from their original position by imposing an irrelevant constraint--*i.e.*, the rate of return on total undepreciated sulphur recovery facilities for a subset of operators shall be at least seven per cent. Furthermore--given the intermingling of past and proposed expenditures--it is unlike unlikely that this proposal constitutes the least-cost method of attaining a given reduction in total sulphur emissions over the province.

A Unifying Summary of the Relationship Between The Theory and Specific Industry Problems

The underlying connection between the theory presented in Chapter II and the Pincher Creek situation described in Chapter IV was clear though often implicit. It may therefore be useful, as a means of summarization, to explicitly relate the economic theory of pollution and pollution abatement to the ensuing litigation.

Returning to first principles, pollution was defined as the deleterious residual by-products which result from production and/or consumption activities. At Pincher Creek, the industrial activity of natural gas processing resulted in residual compounds of sulphur (and also other by-products) which adversely affected the ranchers' production and consumption activities through reduced litters, accelerated corrosion, human afflictions, *etc*. The Pigovian theorists would have proclaimed that an excess of natural gas and a deficiency of agricultural commodities was thereby produced, but Coase (and, for that matter, Buchanan and Stubblebine) would have noted the obvious reciprocal nature of the problem and would therefore have advocated private bargaining. Although the Pincher Creek litigation does have a *prima facie* semblance of such a situation, the resultant settlement can in no way be construed as a full-blooded Coase-type solution. The $700,000 payment was advanced either as a public relations gesture, as the most expeditious method of circumventing the dangerous legal precedent that would have been established if the operators had lost the case, or as a capitulation to possible government pressure exerted immediately prior to an election campaign. Furthermore, in his unbound zest for allocational efficiency, Coase occasionally, of necessity, advocated the bribing of a polluter. Although this tactic will, under certain circumstances, permit the attainment of a Pareto-optimal state, it is likely to encounter considerable psychological resistance at the pragmatic level. Fifth-generation Alberta ranchers simply will not bribe multinational corporation to restore air quality--less harmonious solutions are likely to prevail. Other important factors that would have prevented meaningful private bargaining include: the comparatively-weak financial position of the ranchers; the plaintiffs' lack of easy access to information regarding plant emissions and possible synergistic interactions between them; and, the sporadic nature of the damages.

Clearly, then, the solution to environmental pollution lies not in private bargaining--nor, for that matter, in out of court settlements subsequent to examinations for discovery--but through government-imposed internalization of externalities.

Inasmuch as pollution abatement has the two basic qualities of a public good--user-jointness and non-excludability--some of the theoretical literature in this area was discussed in Chapter II. Samuelson concluded that a Pareto-optimal state could not be attained since benefit taxation would result in a failure to reveal preferences; Breton argued that the true demand for public goods manifested itself at the political level; and Bohm asserted that preferences may, in fact, be _overstated_ at the political level. It is interesting to examine the activities of the Pincher Creek Industrial Research Pollution Committee in this regard: the group was initially established to exert pressure on the government, but resorted, at a later date, to litigation. At the "political" level, one might argue that free-riders could obtain the non-excludable benefits (in the form of reduced emissions, _etc_.,) that the group acquired. On the other hand, might not one expect a "bandwagon" effect at the "lawsuit" level?

The actual fact of the matter is that, of the seventeen families who initially formed the group in 1963, fifteen (and _only_ these fifteen) participated in the out of court settlement eight years later. This phenomenom is much more readily explainable in terms of _sociological_, rather than economic, behavior: many of the families were related, had lived in the region for generations, and clung with stubborn pride to their convictions. Therefore, neither a free-rider, nor a bandwagon, effect was discernible.

Conclusions

The market failure precipitated by environmental pollution can only be alleviated by government intervention. However, the current level of pollution abatement in Alberta is not determined by precise economic criteria, but rather, by a system of standards which display tacit recognition of hidden pollution costs. The system has evolved through a complex interaction of political-pressure groups including, but not confined, to: environmental study groups, influential civil servants, ad hoc alliances formed at public hearings, and last, (but not least), the Alberta petroleum industry. As a result, the theoretically-desirable goal of providing insurance against unknown pollution effects through the reduction of total SO_2 emissions has been slightly constrained by the government's consideration of private profits. However, private sector economic analysis is-- as its name implies-- concerned with the well-being of only a subset of society: anti-pollution regulations must be established in the best interests of society as a whole. We must therefore determine not only the full nature and extent of external costs, but also precisely who pays for pollution abatement.

Limitations of the Study

Due to the overall time constraint, and the large proportion of the total time allocated to examining the theoretical literature and obtaining a good working knowledge of the technical and regulatory aspects of the industry, this thesis has of necessity been of a qualitative, rather than quantitative, nature. It does, however, hopefully attain its objective of relating the basic concepts of environmental economic analysis to an important Alberta problem, and should, therefore, serve to emphasize the contribution that further, more elaborate, socio-economic studies might make.

Suggestions for Further Research

1. A detailed economic study should be initiated to determine the proportional incidence of the cost of pollution abatement equipment on operators, taxpayers, and consumers. Many factors must be considered, including: the extent, if any, to which gas prices can be negotiated upward; the apparent intention of the Alberta government to encourage secondary industry, and hence utilize more natural gas *within* the province; and, the very real possibility that no new contracts for the export of natural gas to the United States will be permitted.
2. The level of pollution abatement will, to a large extent, always be determined by the relative powers of various politically-orientated groups. Therefore, an attempt should be made to determine exactly how each category of citizens perceives the ultimate

costs of pollution abatement as being borne. Although much of our current natural gas production is exported to other parts of Canada and to the United States, the perfected research technique could later be applied to other areas of environmental concern, such as refinery pollution.

3. Several partial or total exemptions from enhanced sulphur recovery guidelines have been granted to operators on the basis of "detrimental plant economics." Aside from the immediate objection that economic inefficiency from the standpoint of the firm may well imply a greater degree of economic efficiency in the economy as a whole if externalities are eliminated, it would appear that the forecasts of future sulphur prices utilized in granting the exemptions have become outdated. A new, comprehensive analysis of supply and demand conditions in the sulphur industry is therefore in order. Exemptions from the guidelines should be re-assessed every two years, and operators who do succeed in remaining exempt should be required to make an annual contribution to a fund established to promote research into the long term effects of low level sulphur pollution.

4. A concerted effort must be initiated to quantify as many of the various types of external costs as

possible. Three possible techniques are listed below:

a. An in-depth study of the production techniques of selected farmers from affected areas should be conducted as a means of assessing the full extent to which their efficiency is diminished by air pollution.

b. Further field studies should be designed in order to more fully assess the effects of air pollutants on crops, animals, and rates of corrosion: eventually, it may be possible to impute an approximate economic value to detrimental side-effects.

c. A questionnaire approach might be of some utility in certain areas. It must, however, be carefully designed so as to ensure that no perceived incentive exists to overstate the true costs of pollution, and this may well prove to be a formidable task.

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